

The History of Robotic Mars Landings

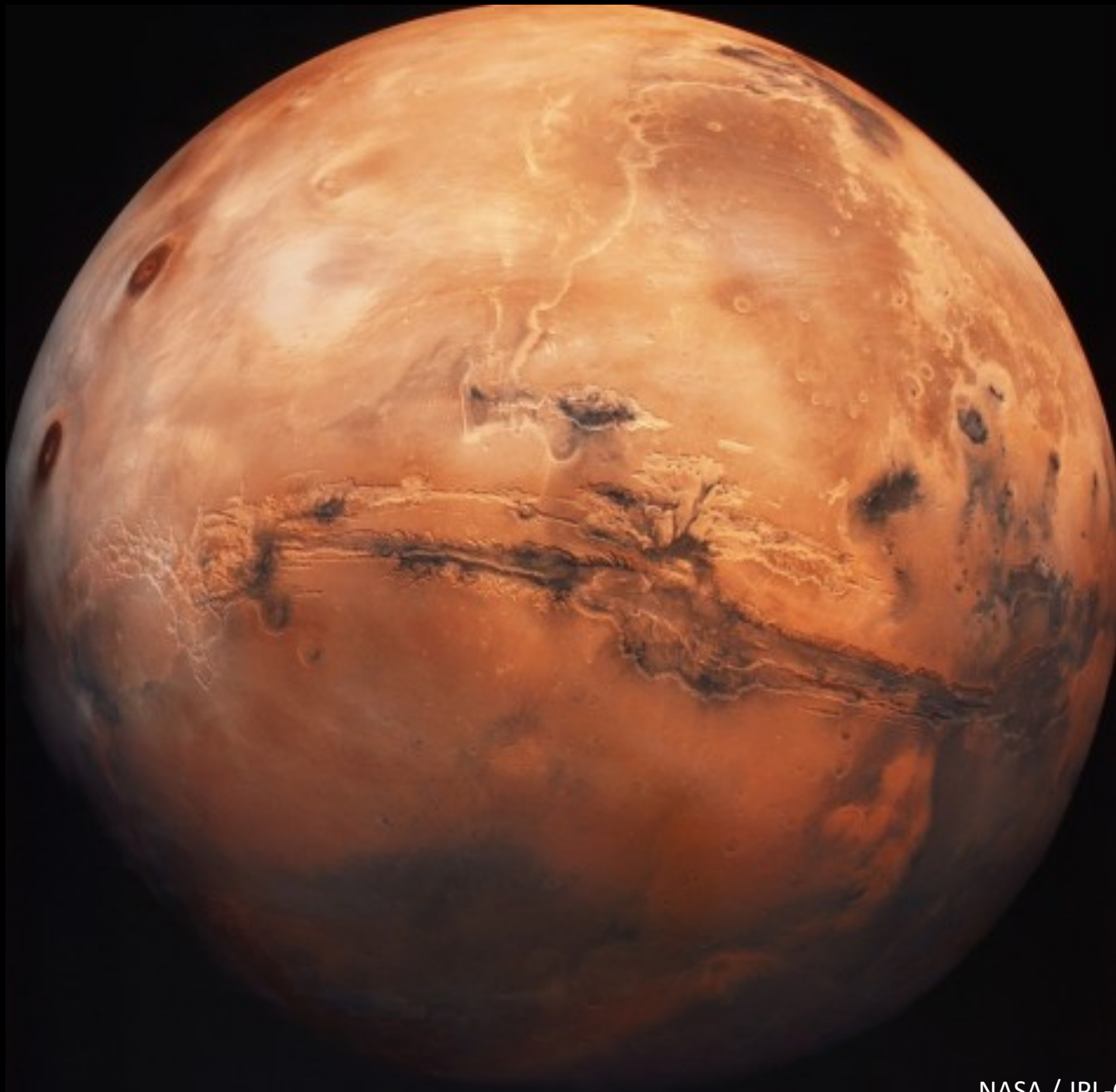
Miguel San Martin

Jet Propulsion Laboratory, California Institute of Technology

**2018 Cyber-Physical Systems Principal Investigators'
Meeting**

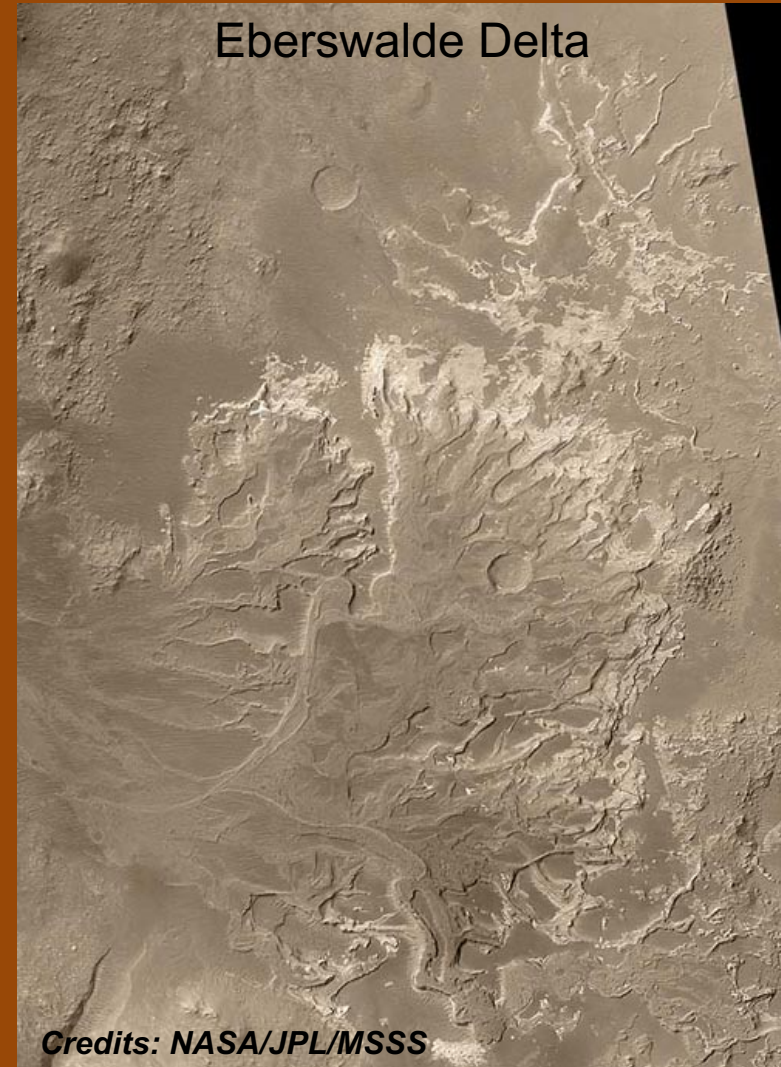
Alexandria, Virginia

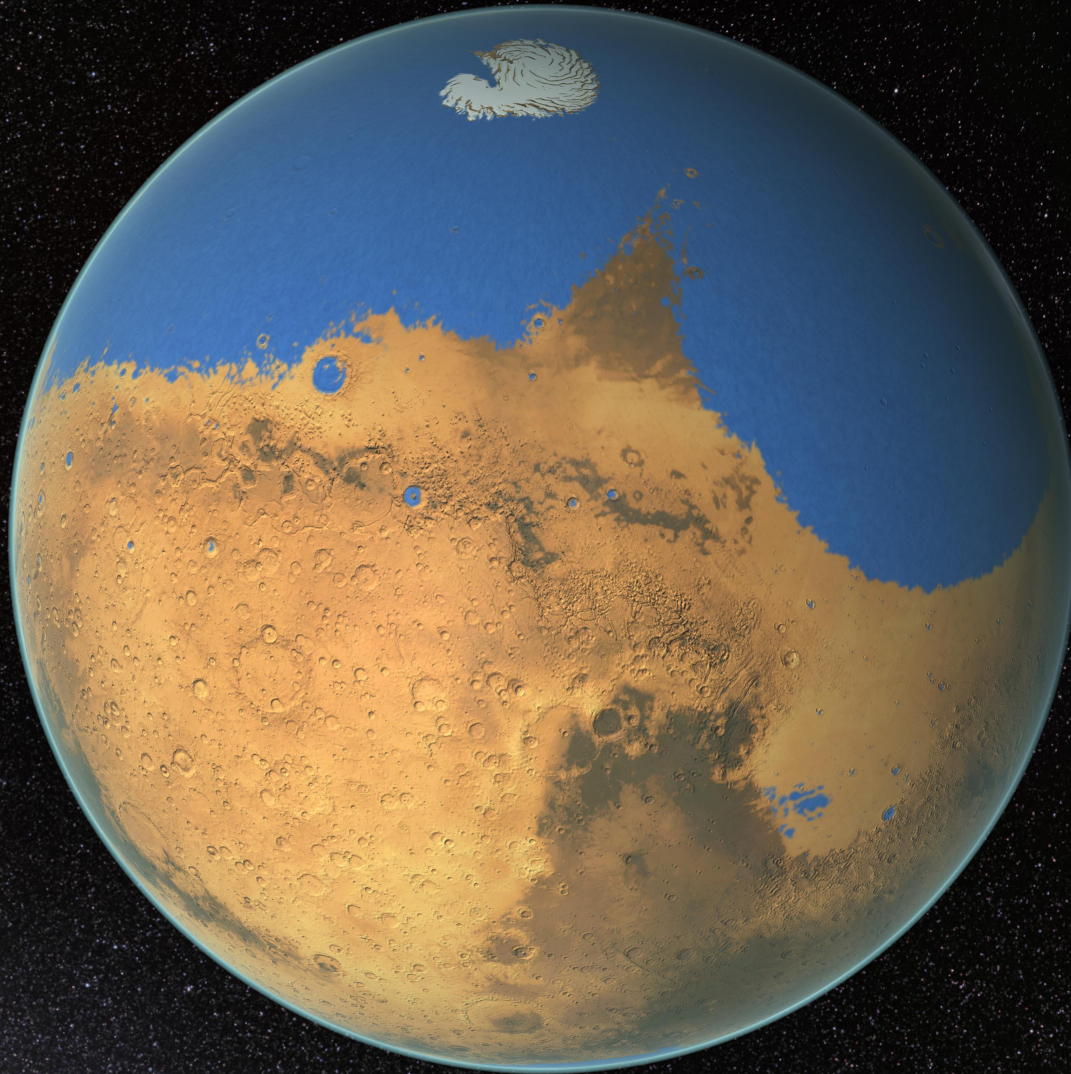
November 16, 2018



Why Mars?

- There is scientific evidence that Mars was once a warm and wet planet like Earth and, therefore, it might have had the conditions necessary for the origin of life.
- If we find evidence of life on Mars, past or present, it would be an important step in answering the question of whether we are alone in the universe.
- Mars is the most habitable of the planets and therefore the most adequate for its colonization.





Scientists estimate that 4300 millions years ago, Mars had enough liquid water to cover 19% of its surface!

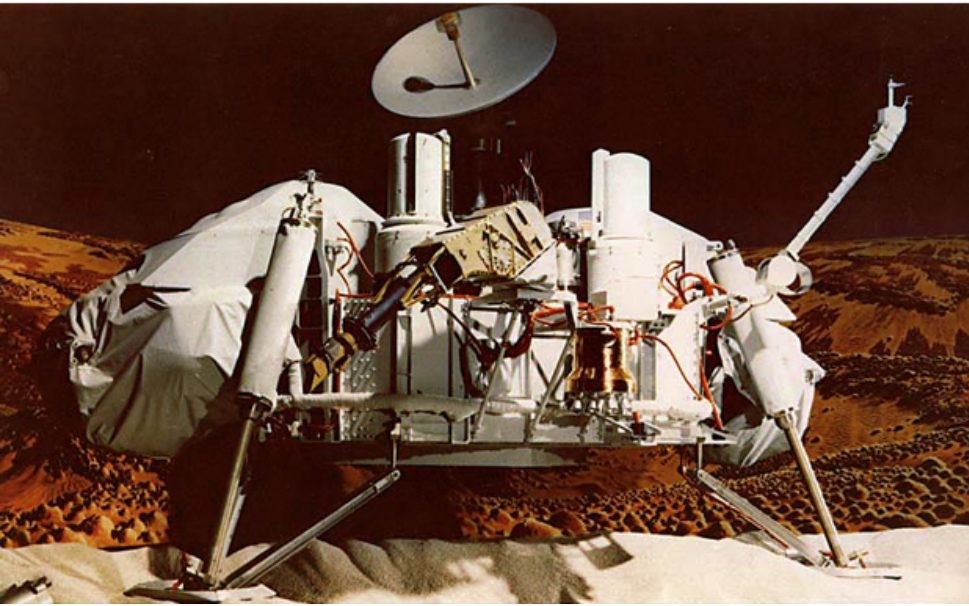
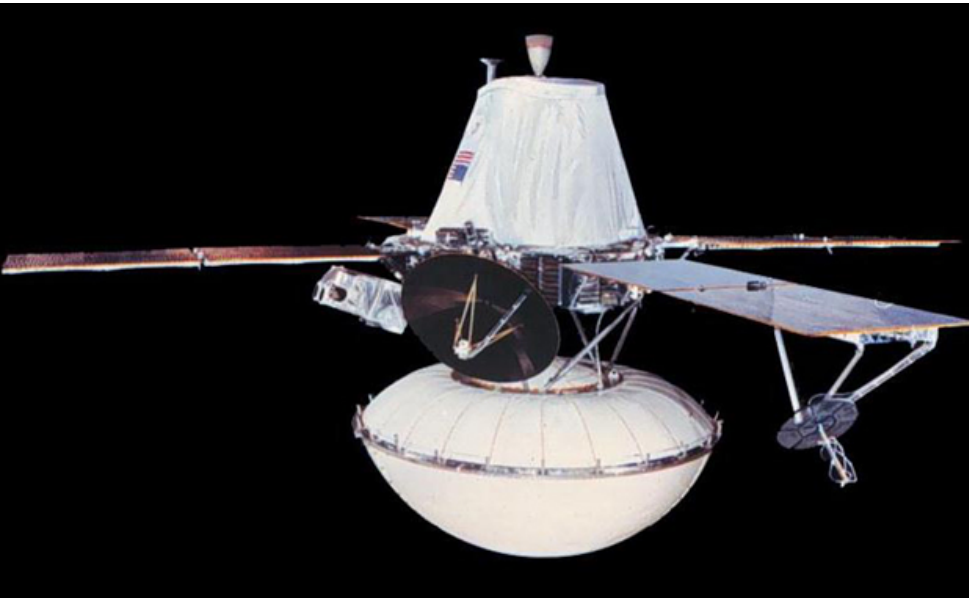
Viking I & II (1976)

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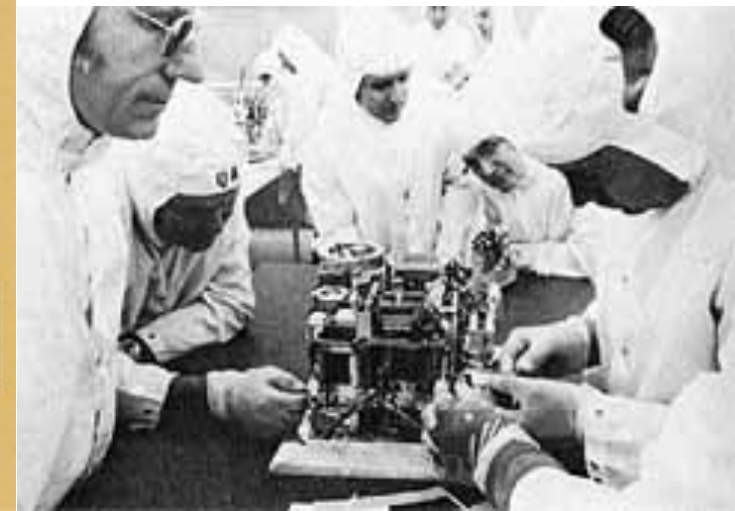
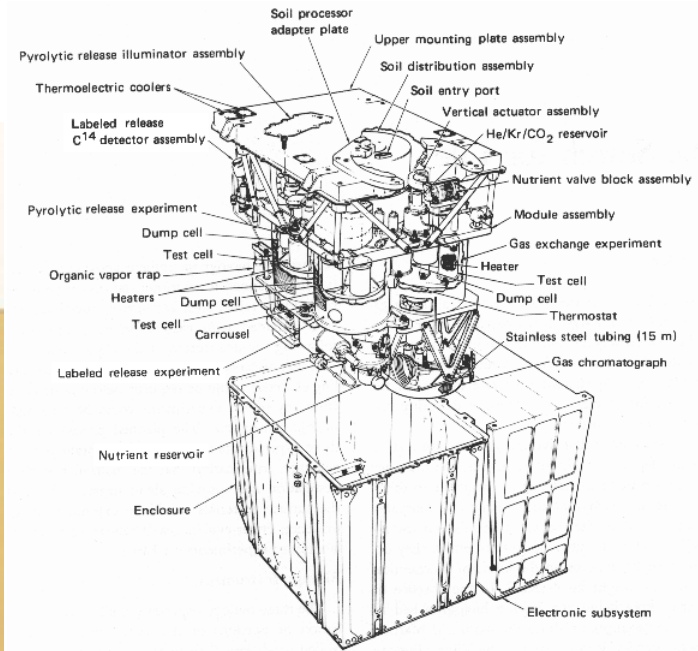
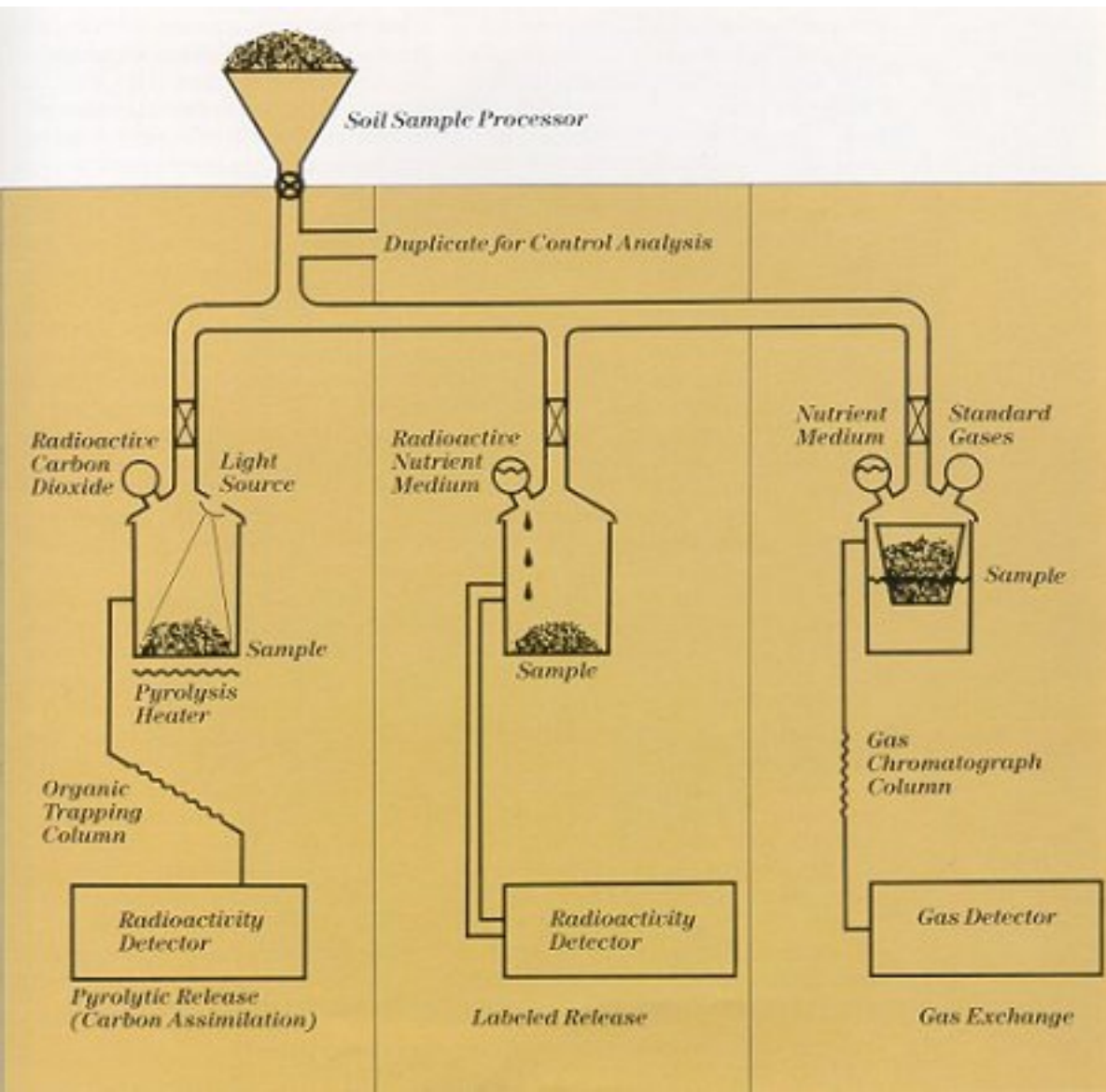




Viking (1976)



Viking Biological Instruments



Viking I

Chryse Planitia

20 de Julio, 1976



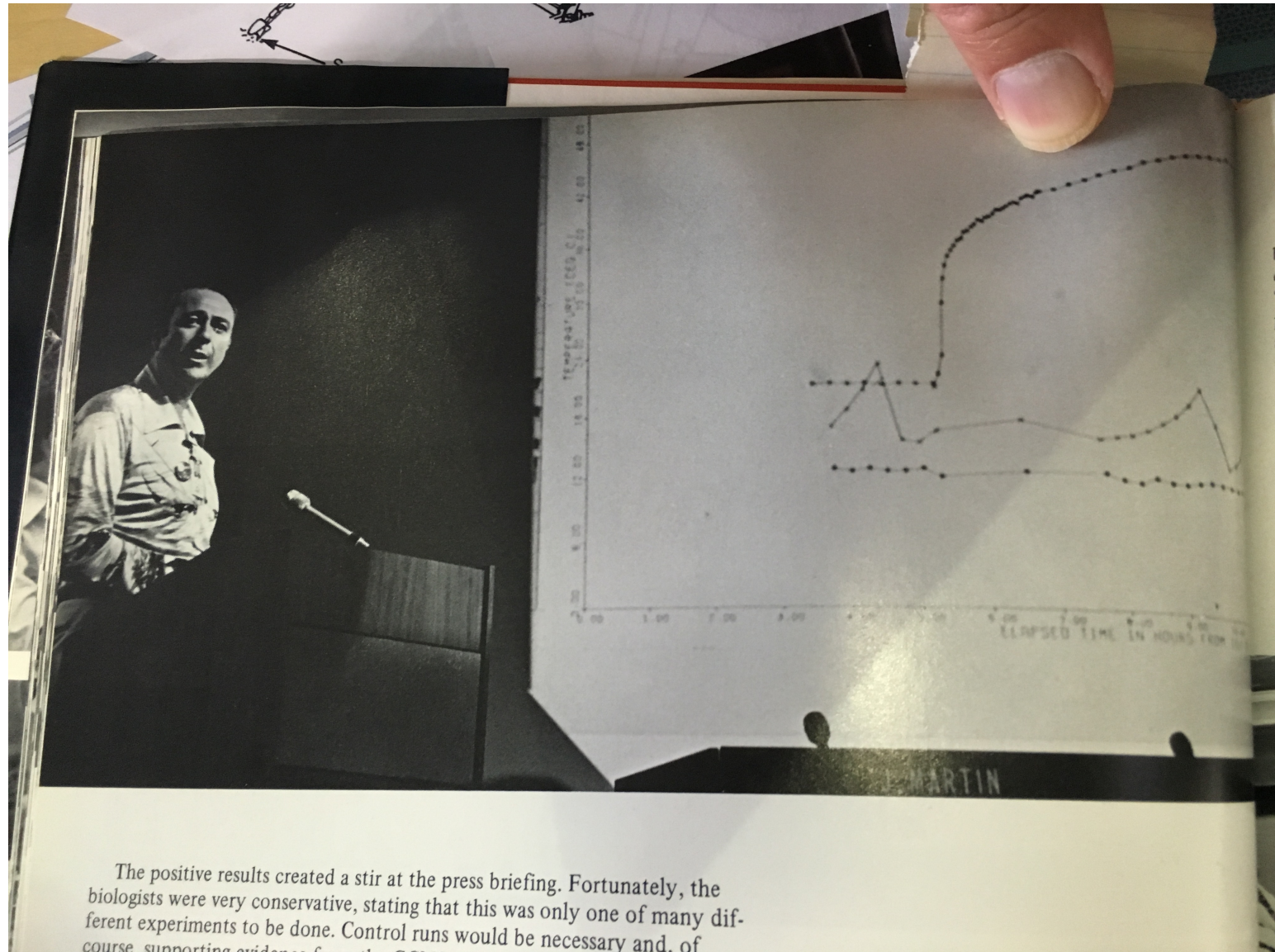


Viking I and Big Joe



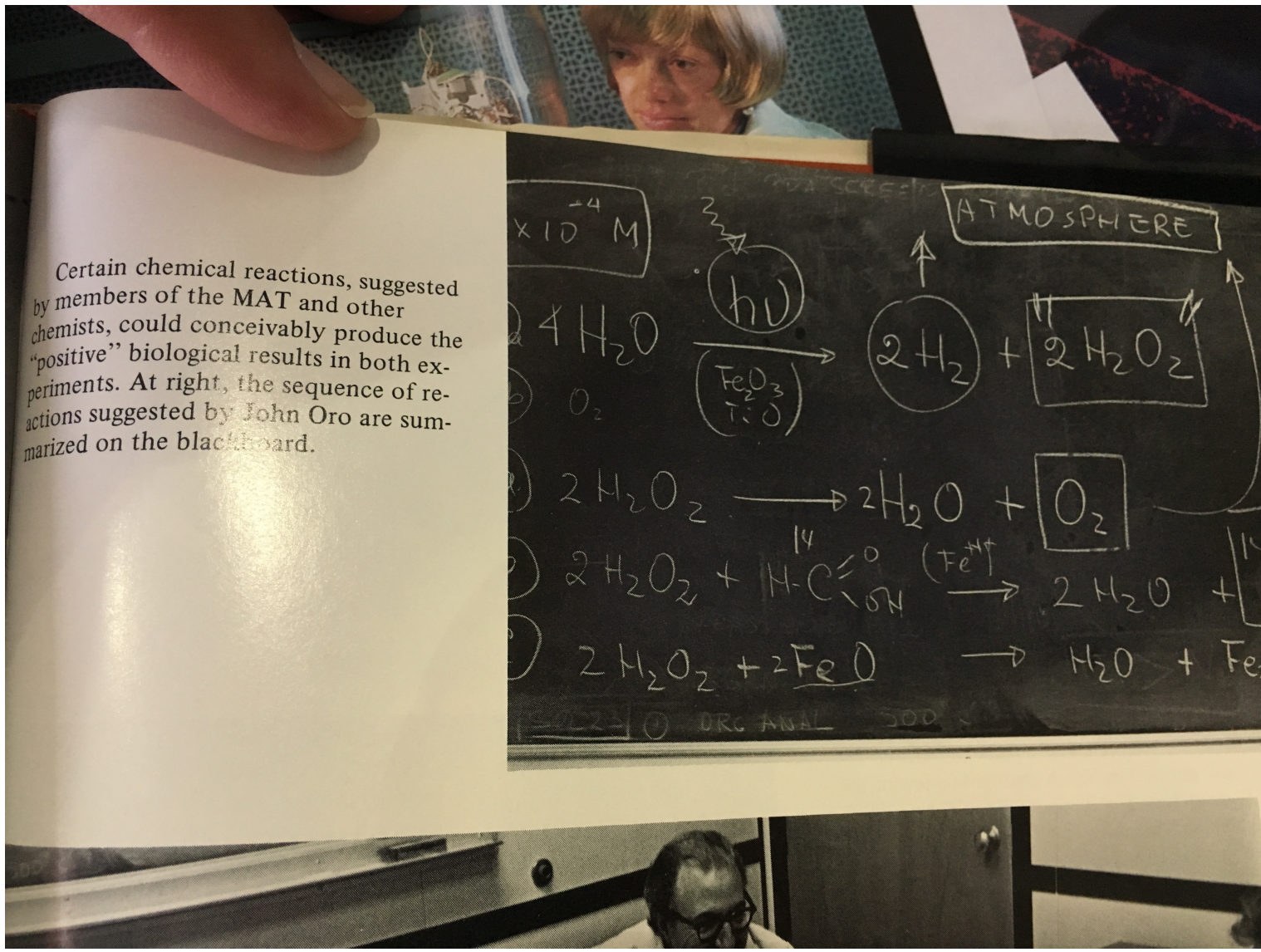


Labeled Release Experiment: The Results

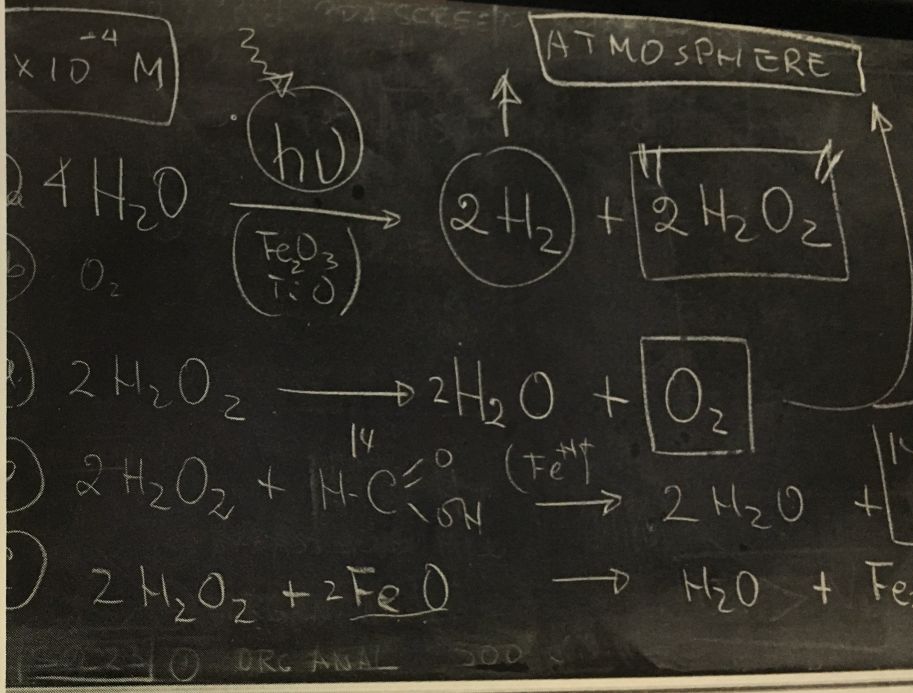




Labeled Release Experiment: No Life!!



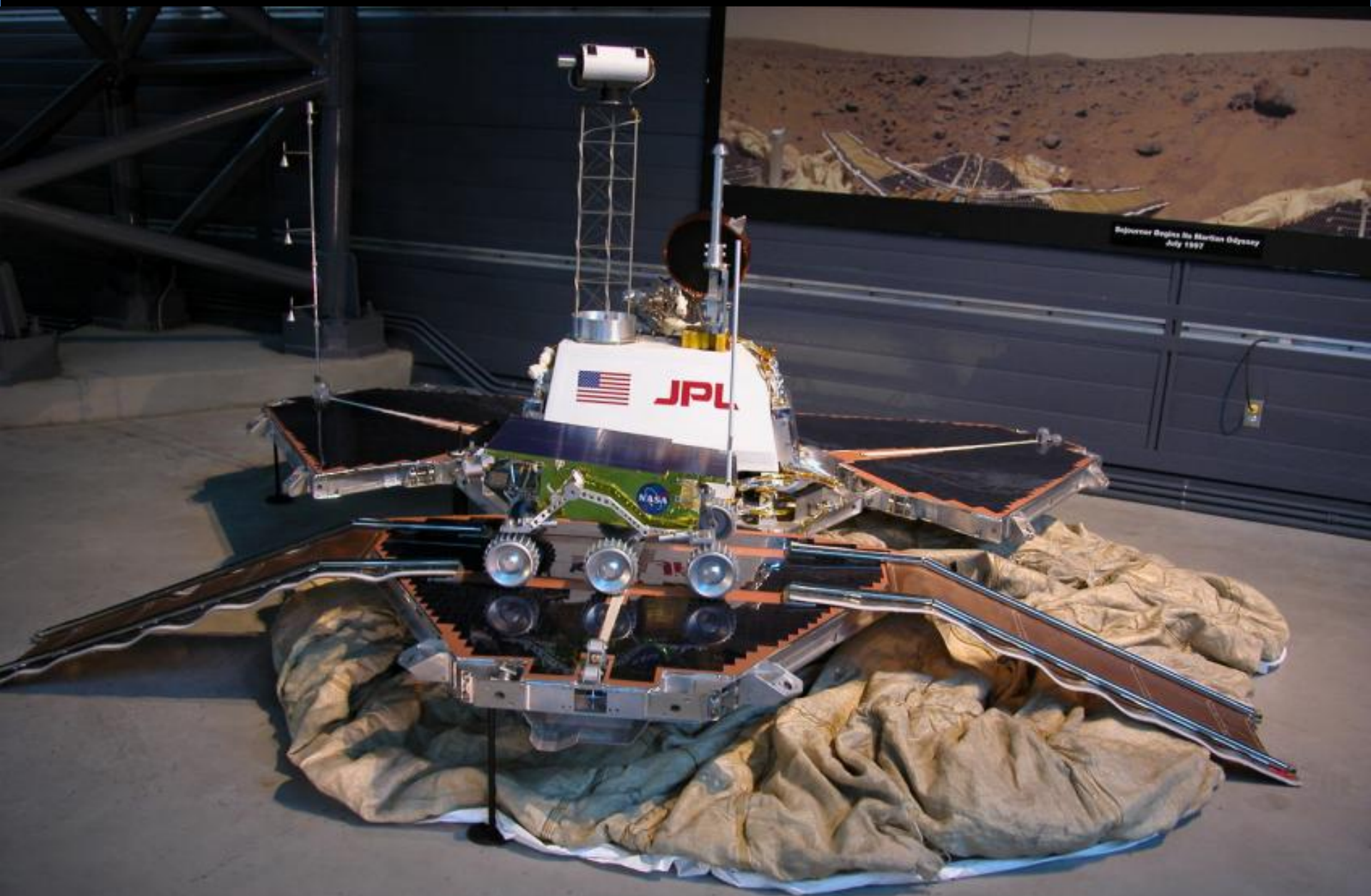
Certain chemical reactions, suggested by members of the MAT and other chemists, could conceivably produce the "positive" biological results in both experiments. At right, the sequence of reactions suggested by John Oro are summarized on the blackboard.







R.I.P.
Mars Exploration
1964-1976



Credit: National Air and Space Museum

The Mars Science Strategy: “Follow the Water”

- When was it present on the surface?
- How much and where?
- Where did it go, leaving behind the features evident on the surface Mars?
- Did it persist long enough for life to have developed?

WATER

LIFE

Understand the potential for life elsewhere in the Universe

CLIMATE

Characterize the present and past climate and climate processes

GEOLOGY

Understand the geological processes affecting Mars' interior, crust, and surface

Prepare for Human Exploration



Develop Knowledge & Technology Necessary for Eventual Human Exploration

When • Where • Form • Amount

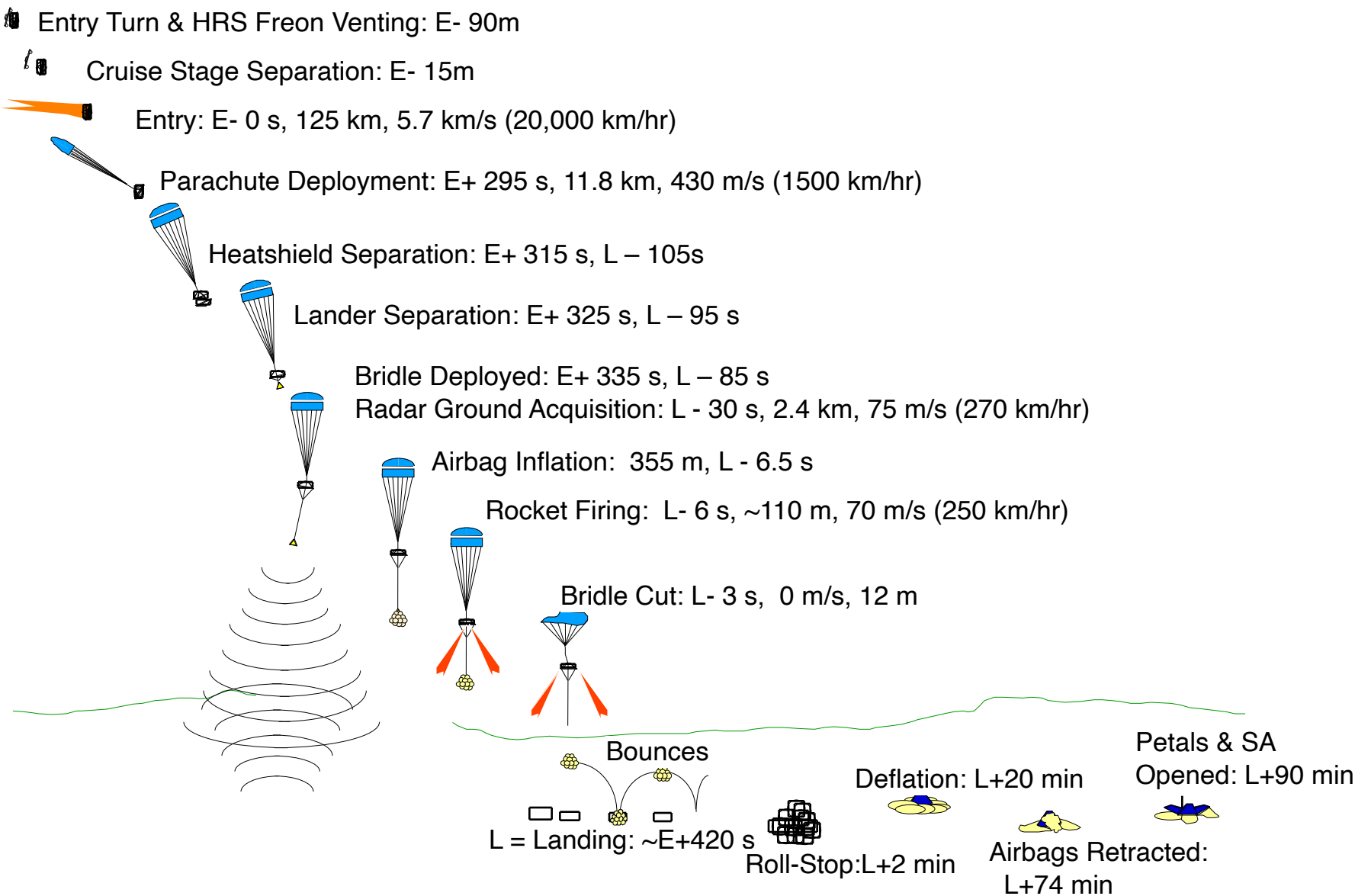
Credit: NASA/Orlando Figueroa

Mars Pathfinder (1997)

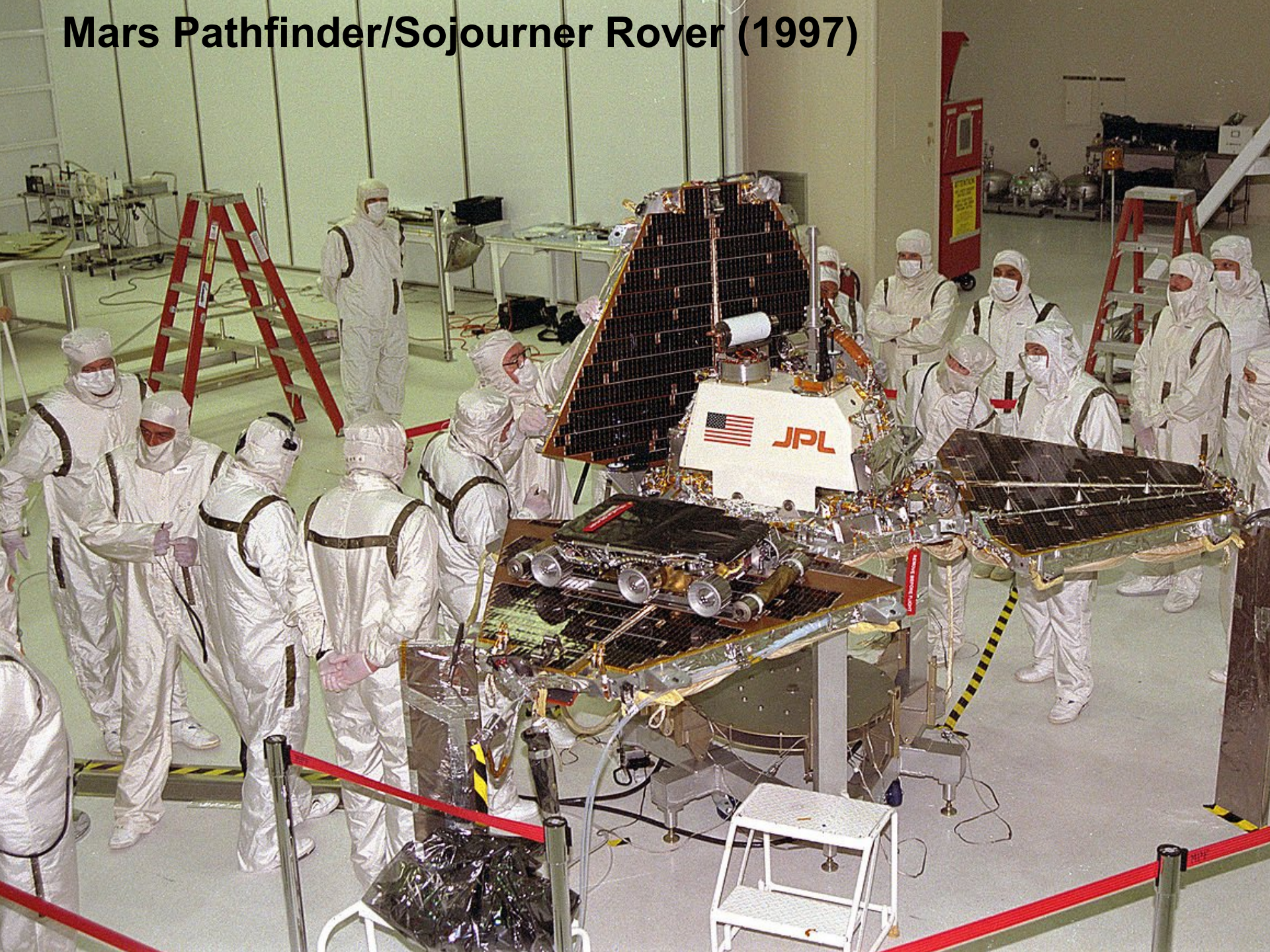




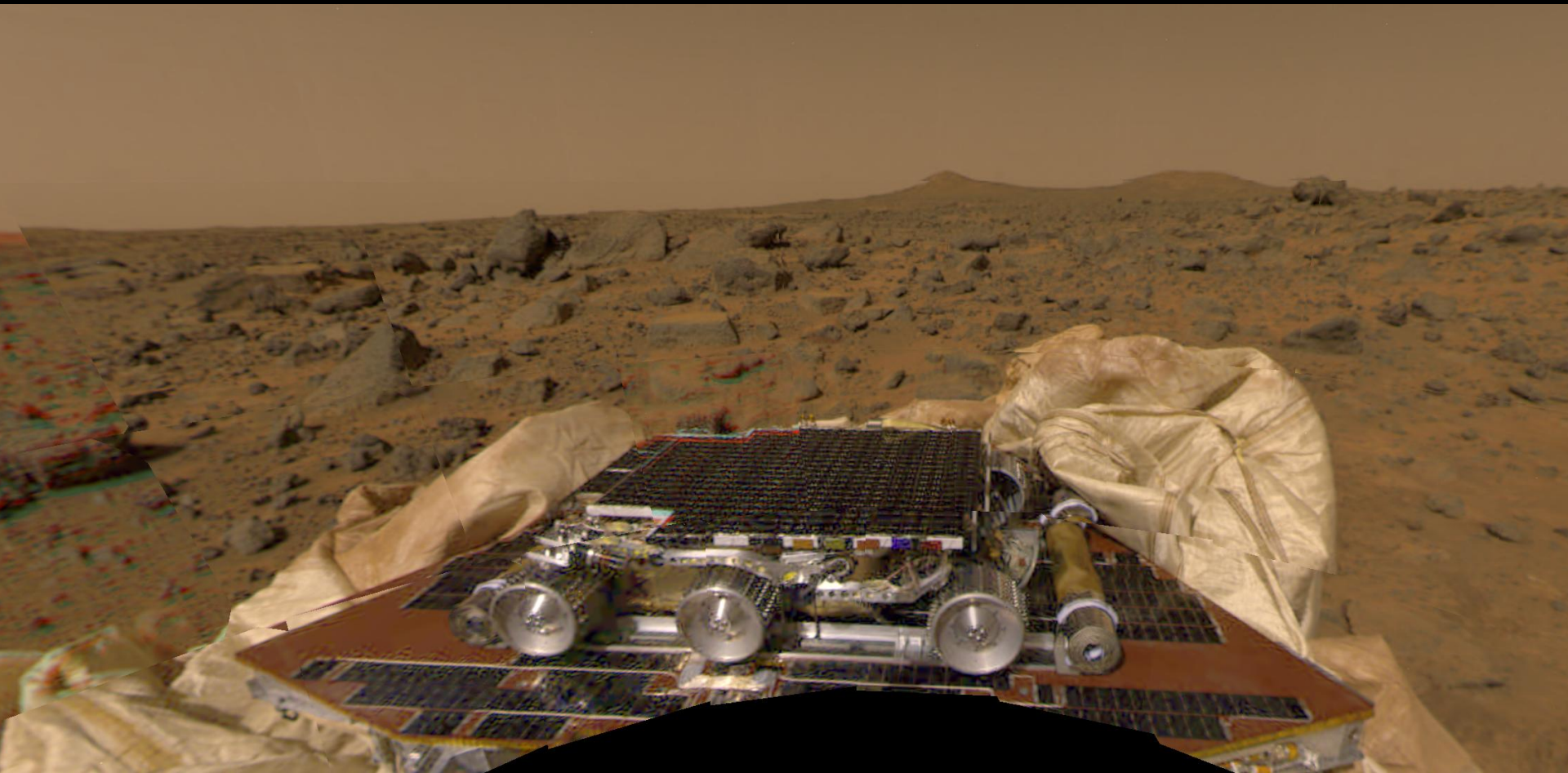
Entry, Descent & Landing Timeline



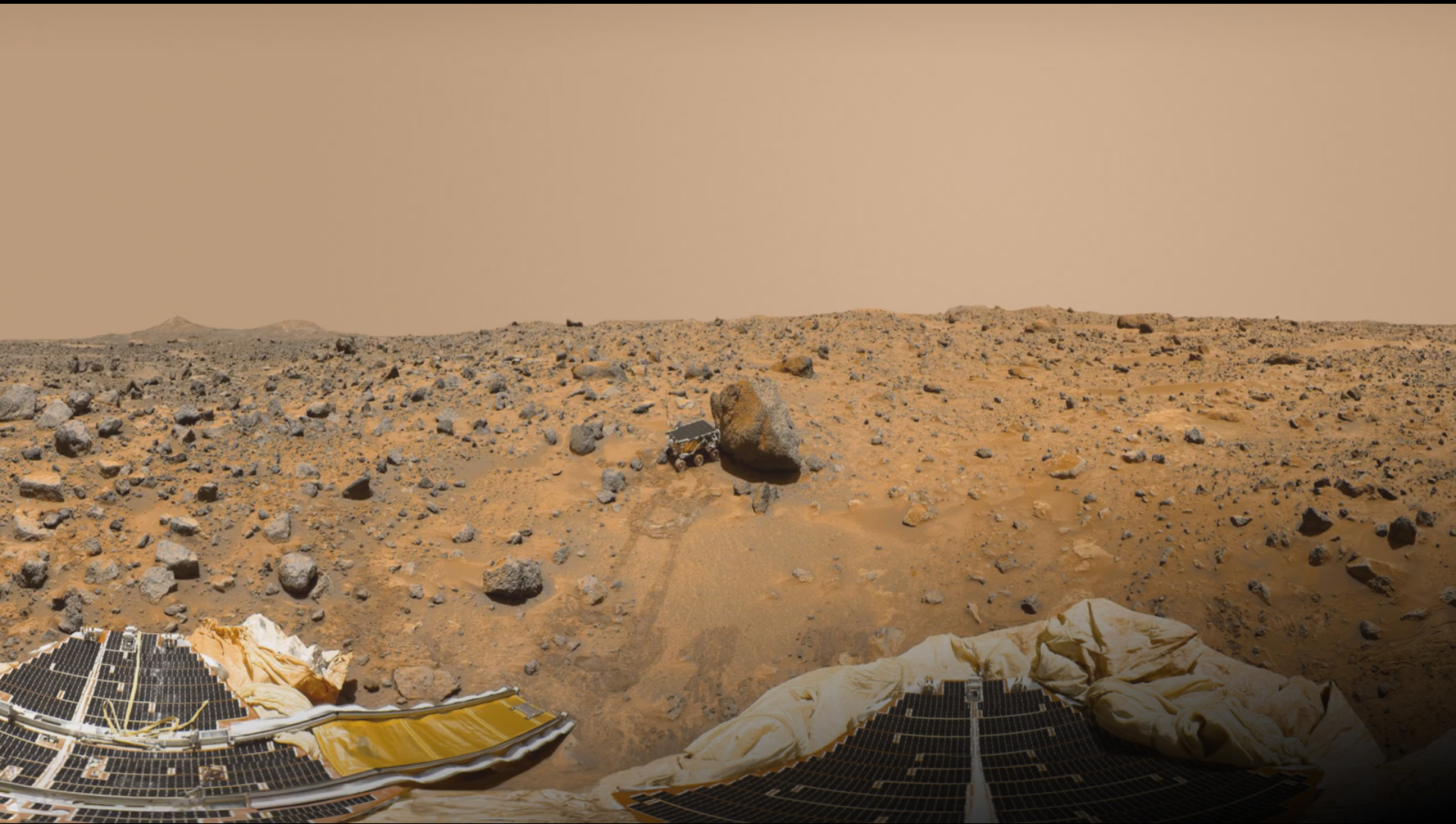
Mars Pathfinder/Sojourner Rover (1997)



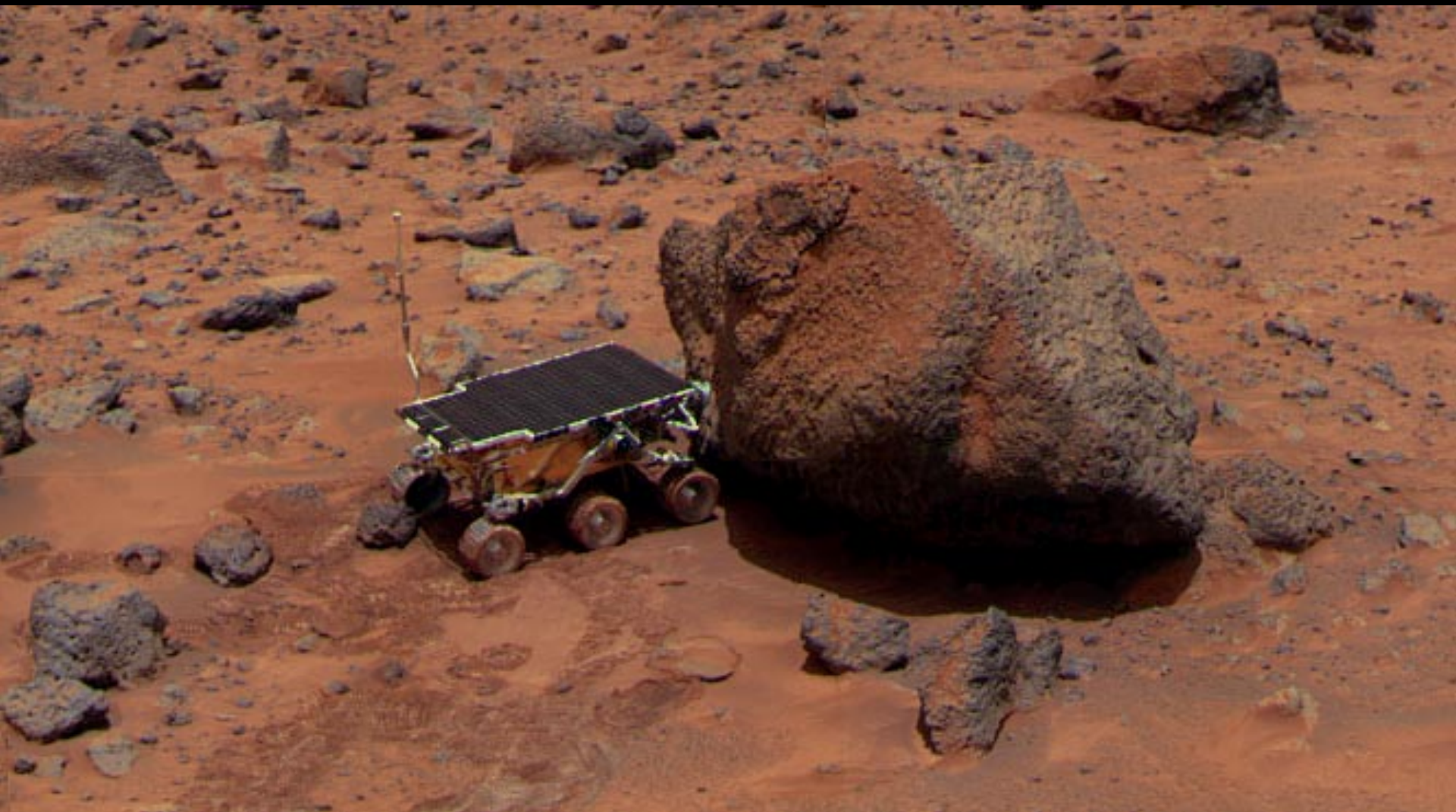
4 de Julio, 1997



Mars Pathfinder/Sojourner Rover

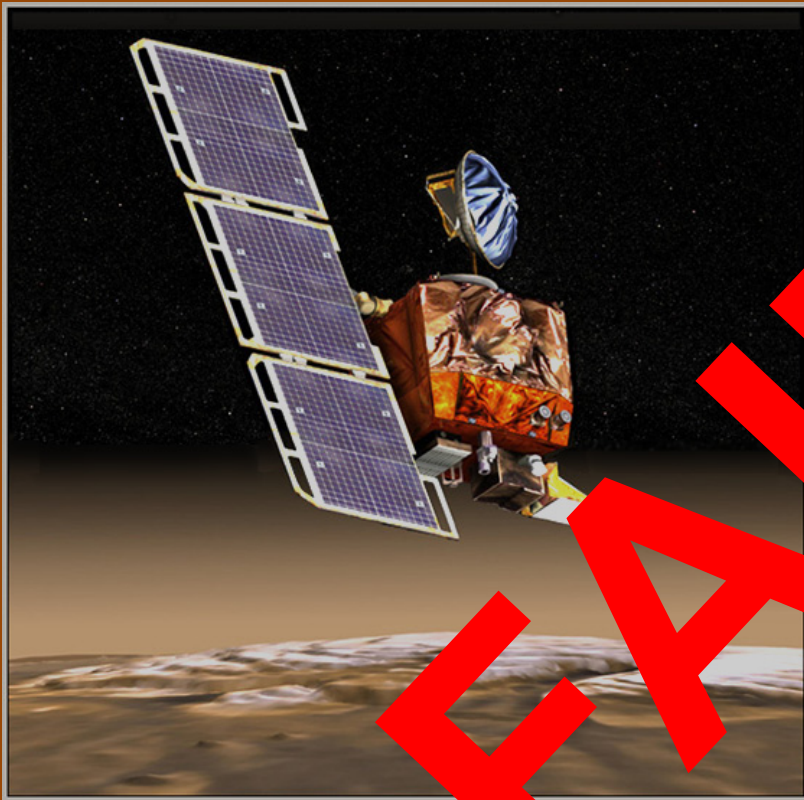


Sojourner Rover y Yogi



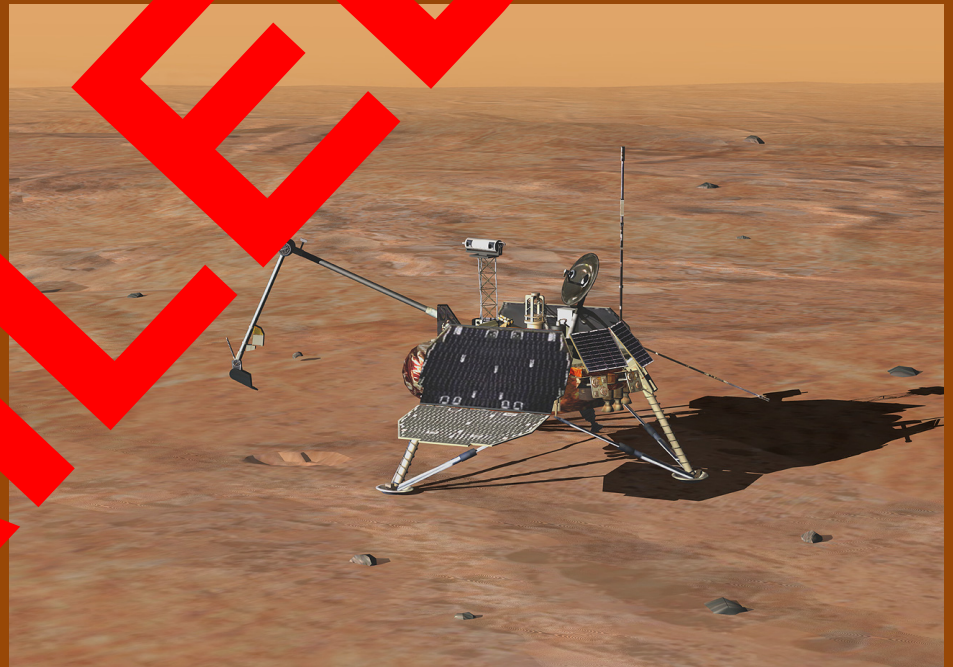


Mars Climate Orbiter



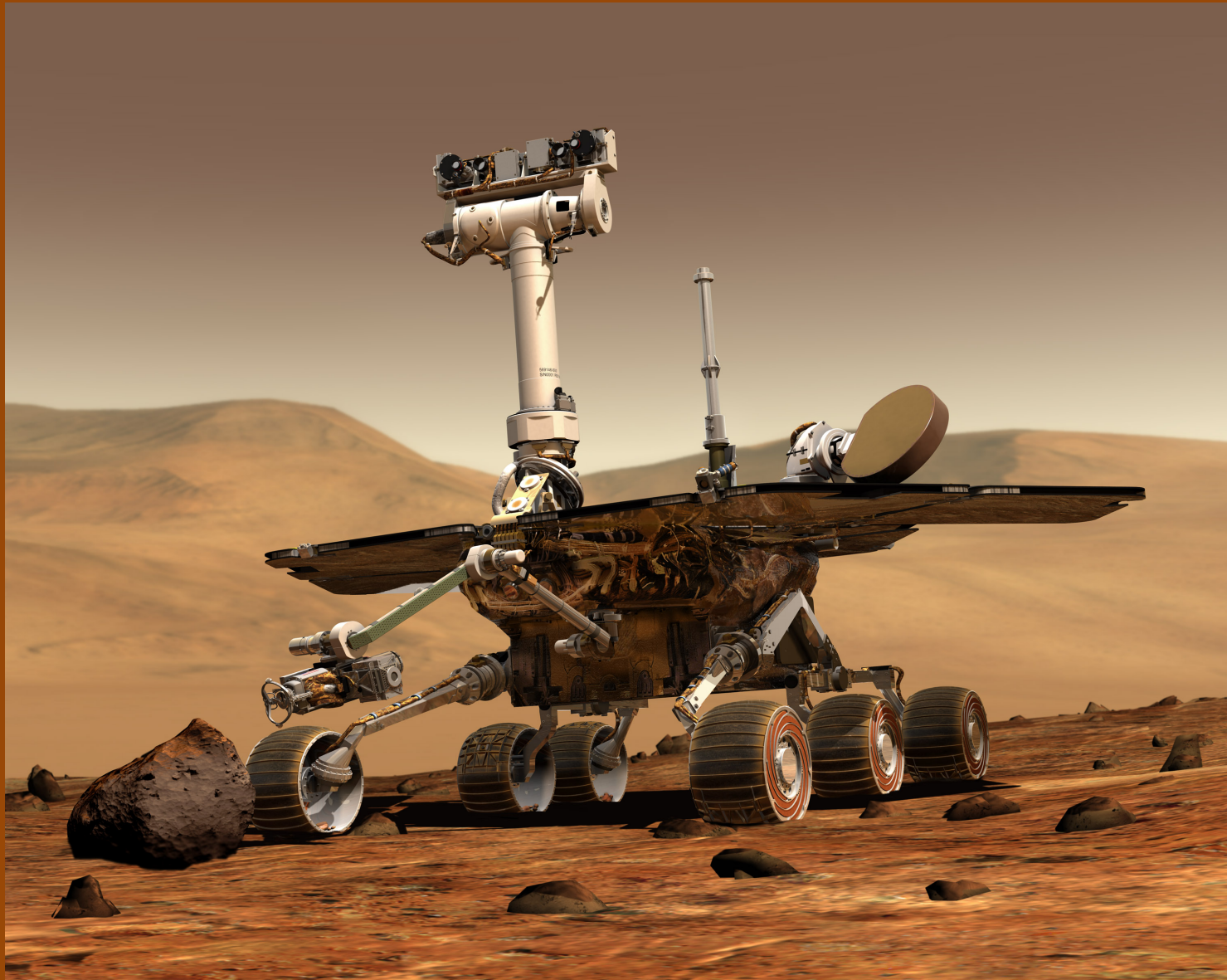
September 23, 1999

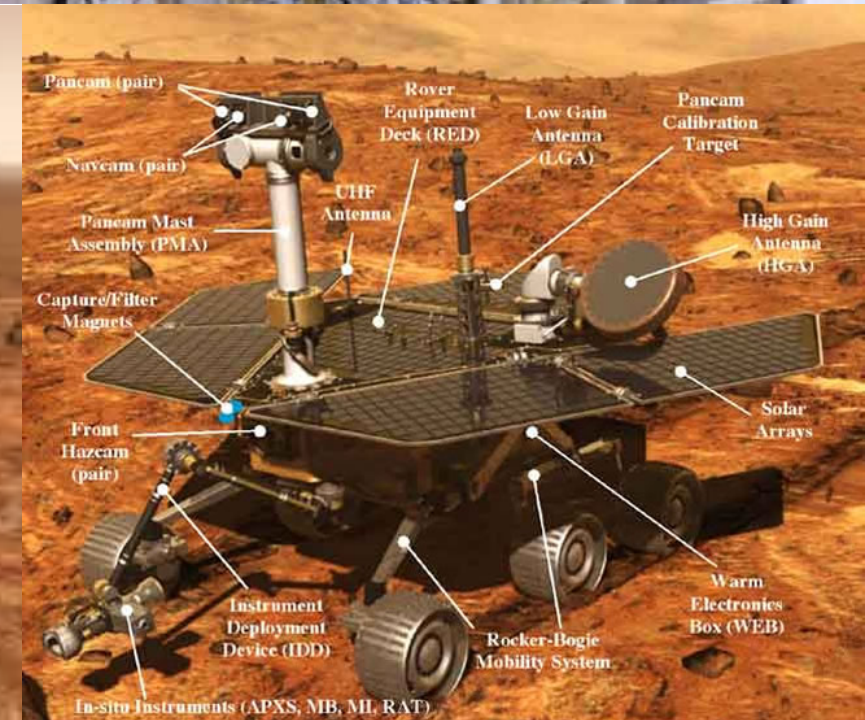
Mars Polar Lander



December 23, 1999

Spirit/Opportunity Rovers (2004)







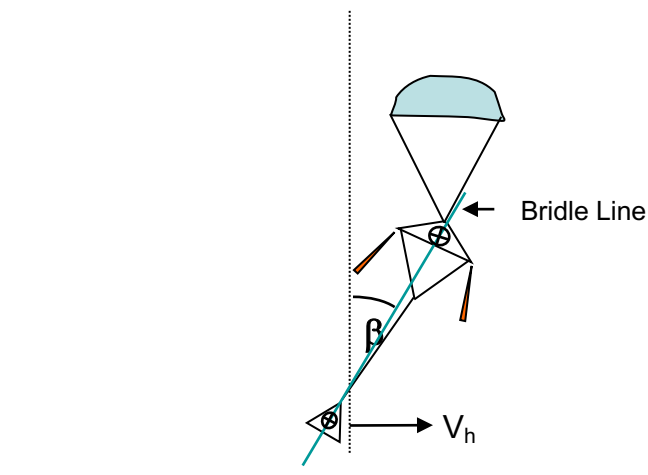




Wind Induced Horizontal Velocity

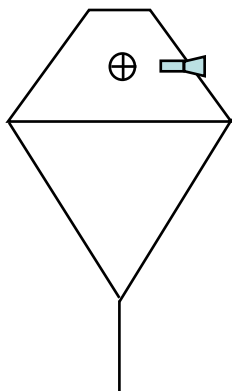
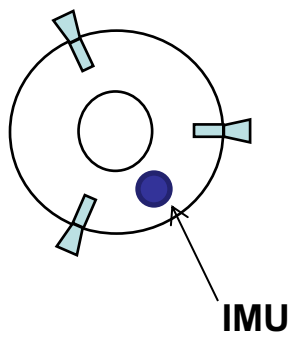
Initial Horizontal Velocity RAD Induced Horizontal Velocity

$$V_h(t_{bc}) = V_h(t_{RAD}) + \int F_{RAD}/m * \sin(\beta) dt$$

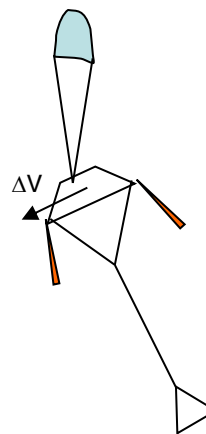




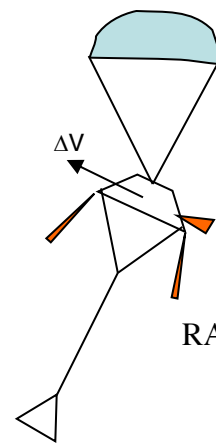
TIRS Control



Bridle Cut



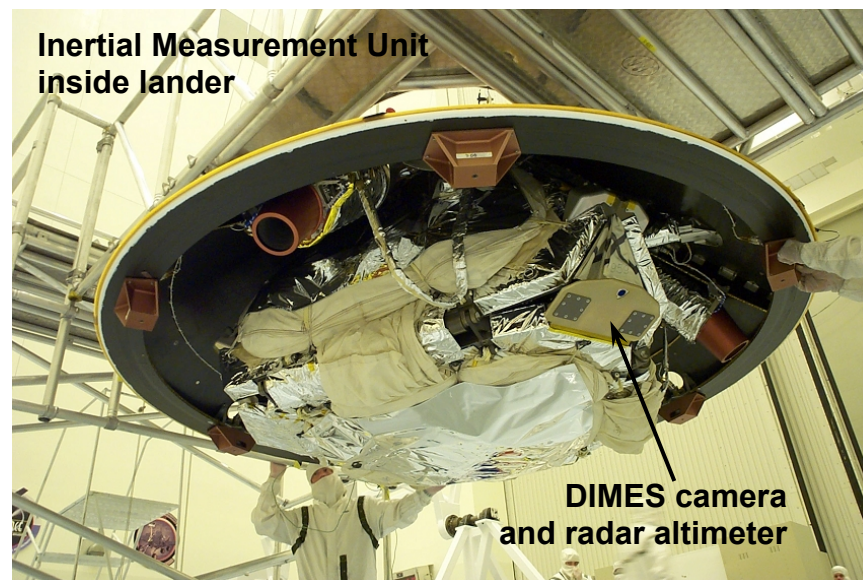
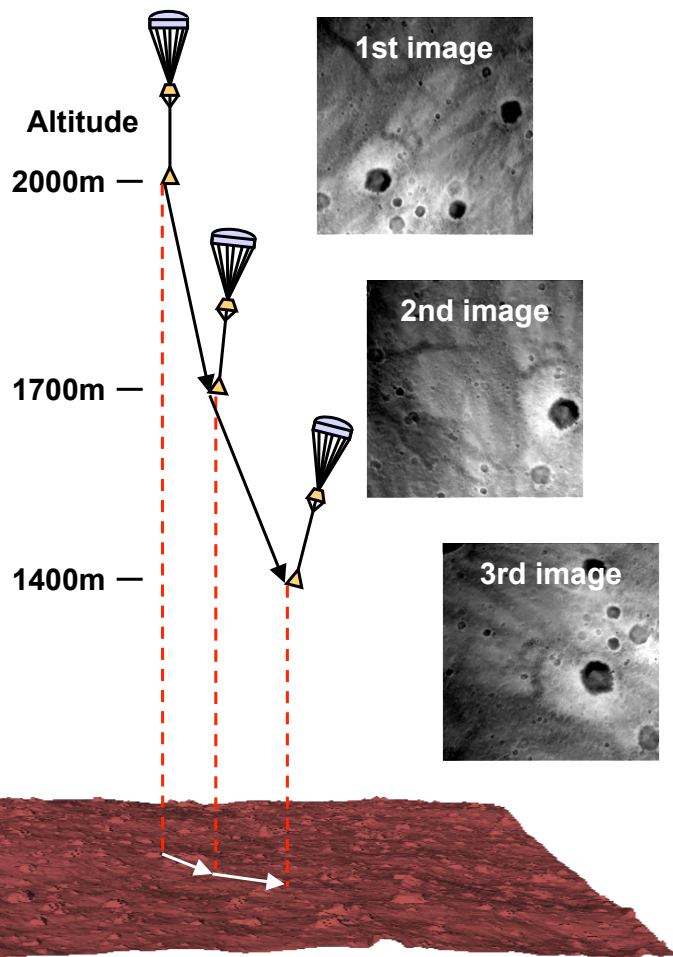
RAD Ignition



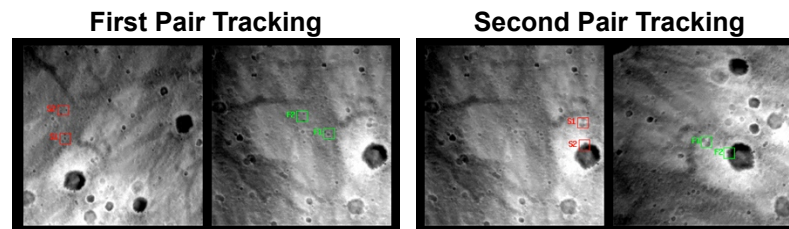


Descent Image Motion Estimation System (DIMES)

DIMES SCENARIO

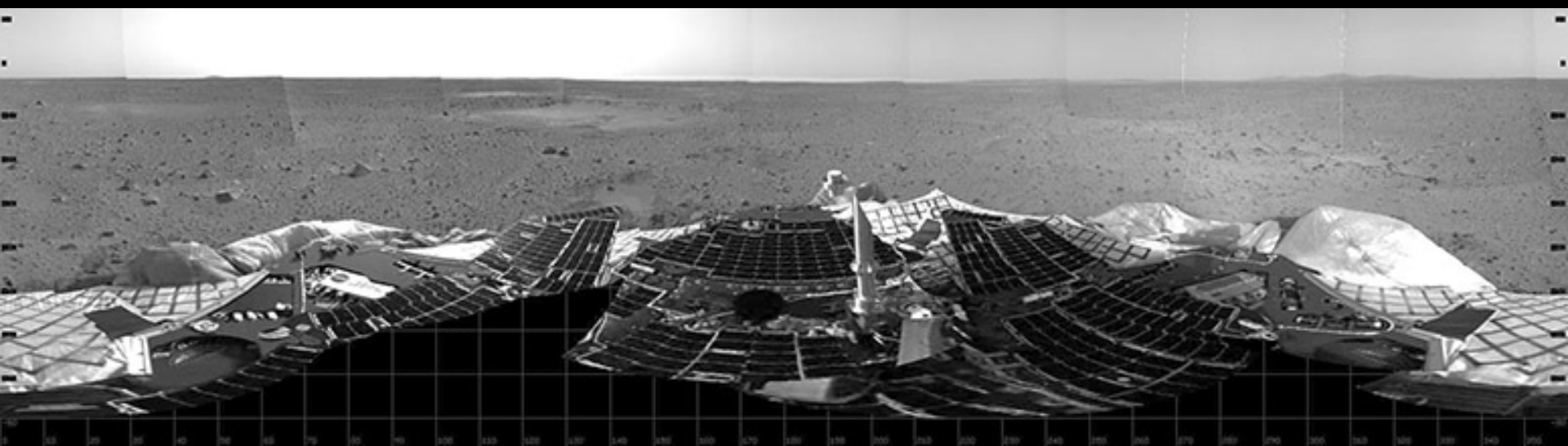


DIMES RESULT

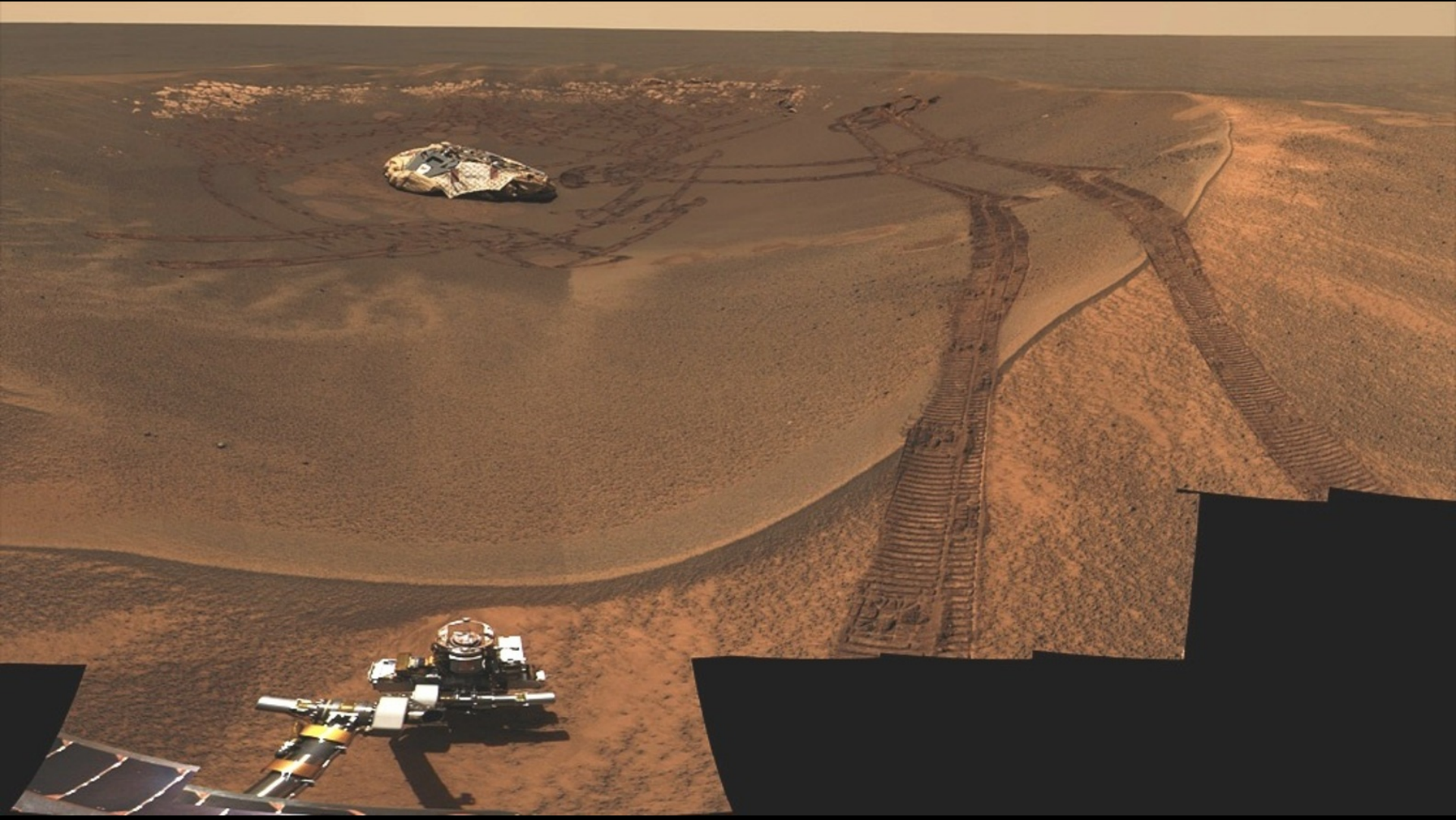


MER-A/Spirit, Gusev Crater, January 4th, 2004

Spirit First Panorama



Opportunity in Aguila Crater





2012
*Curiosity
Rover*

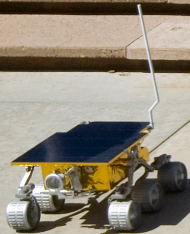


2011
*Electric Mini
Cooper*

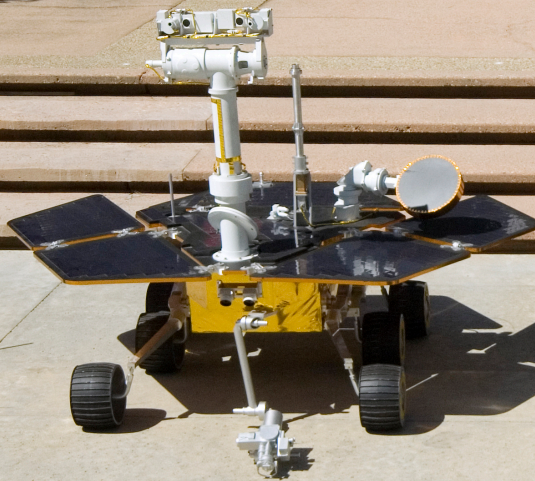
Mars
Science
Laboratory
2012

Mars
Exploration
Rovers
2004

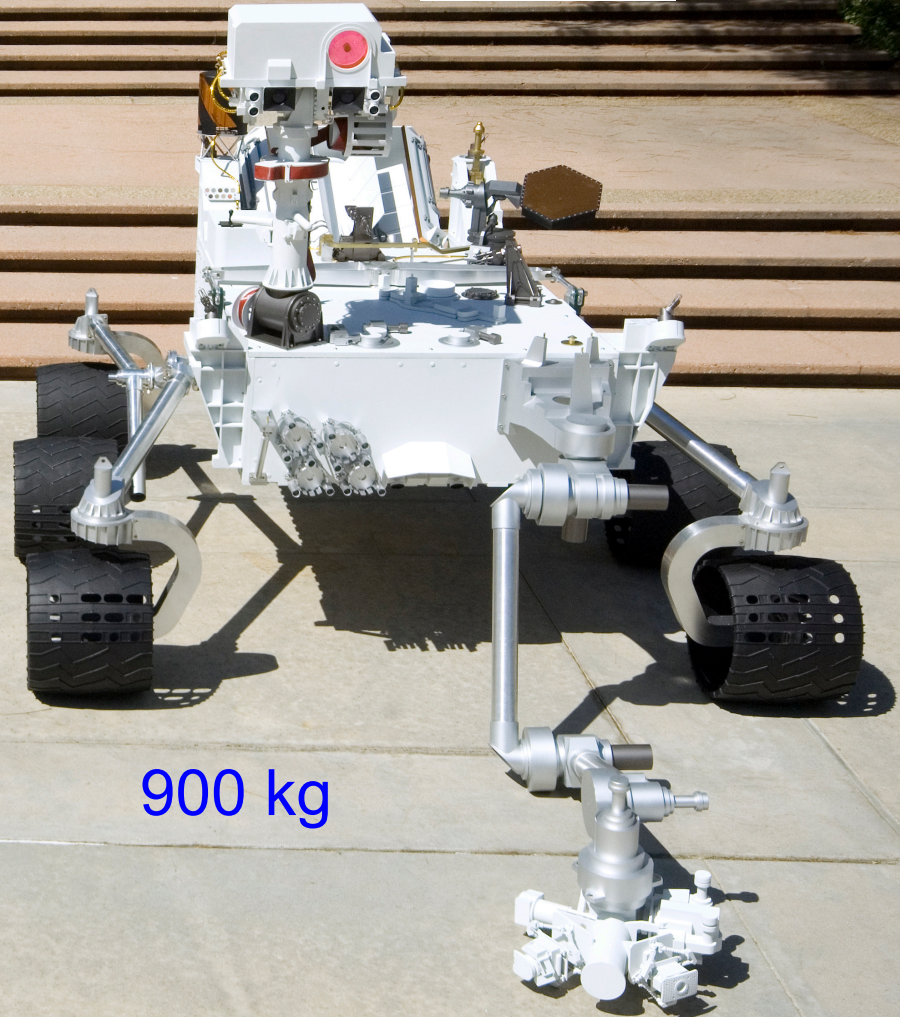
Mars
Pathfinder
1997



15 kg



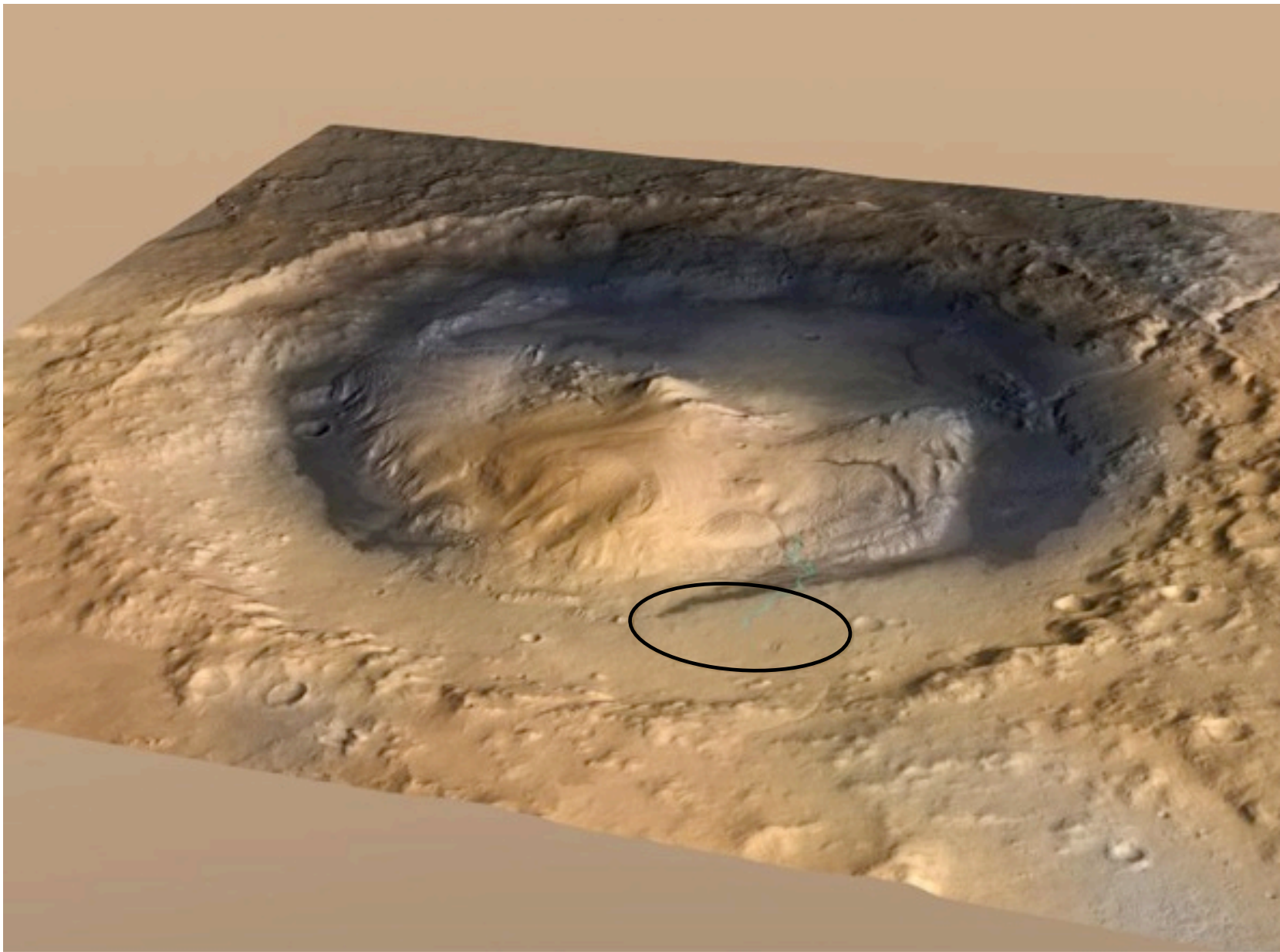
175 kg

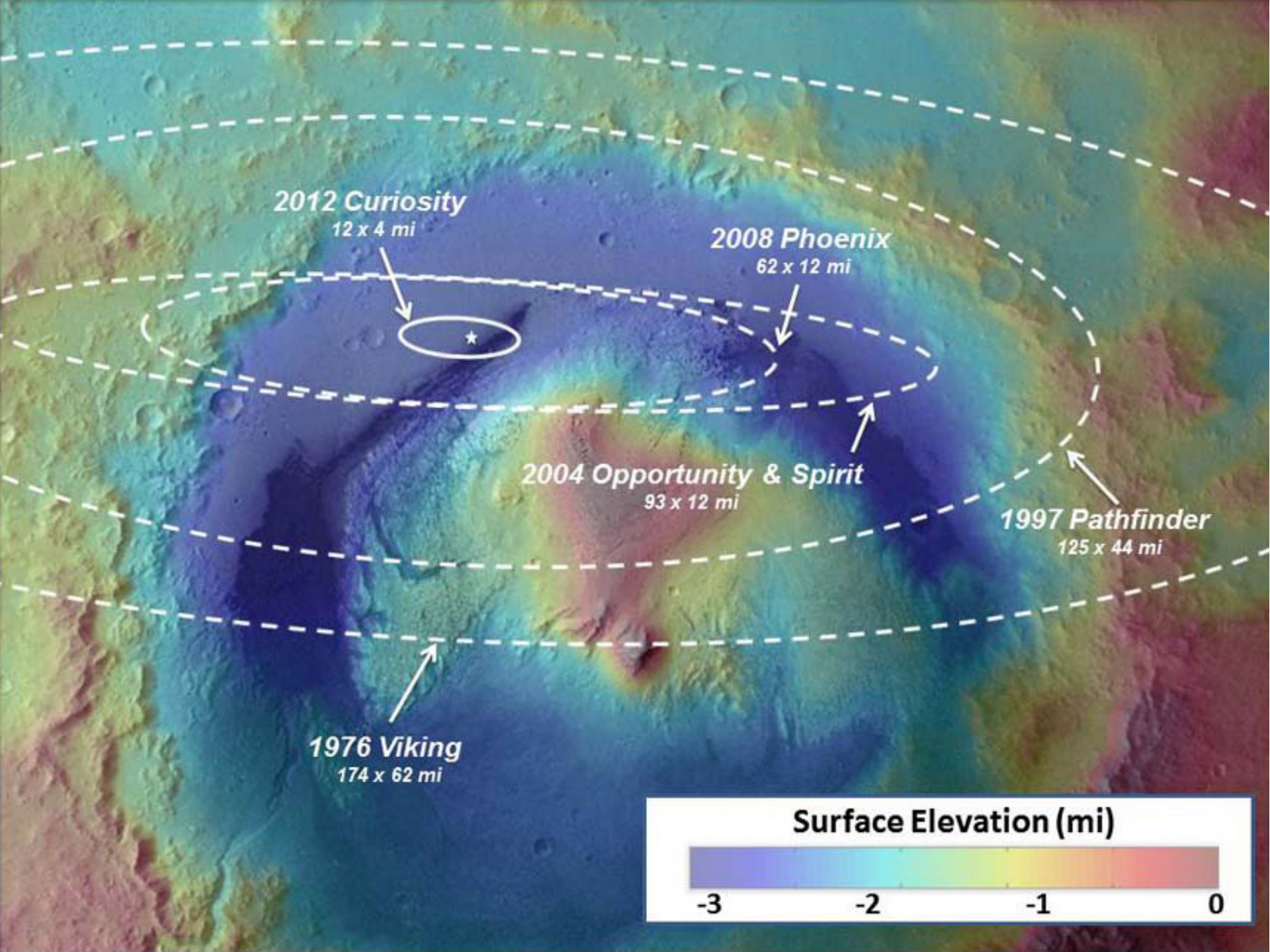


900 kg



MSL/Curiosity Landing Ellipse in Gale Crater







Entry, Descent, and Landing Phases

The 7 Minutes of Terror

20,000 km/h ($E = 100\%$)
125 km

Entry
~4 minutes

1,500 km/h ($E = 1\%$)
10 km

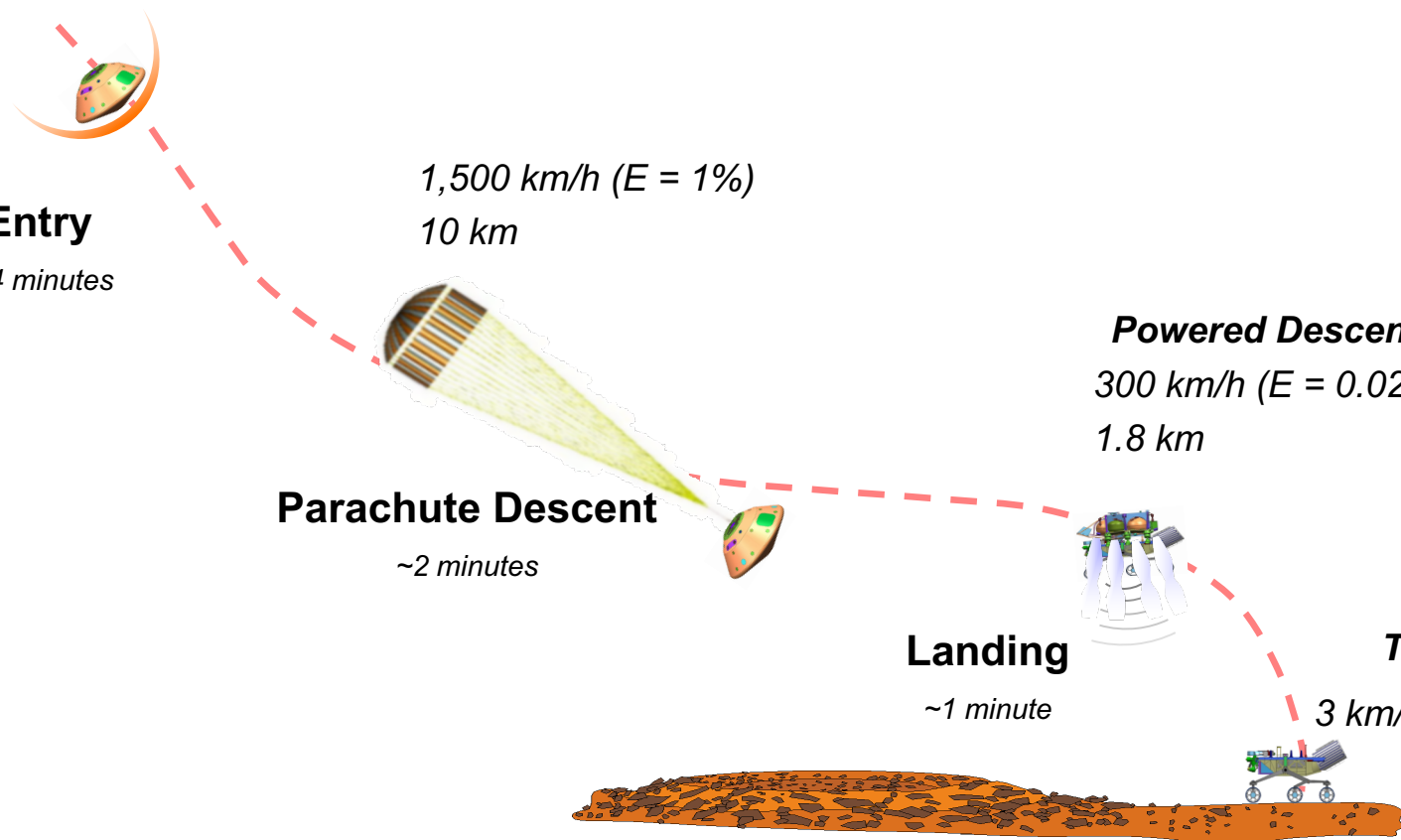
Parachute Descent
~2 minutes

Powered Descent
300 km/h ($E = 0.02\%$)
1.8 km

Landing
~1 minute

Touchdown

3 km/h ($E = 2 \cdot 10^{-6}\%$)





Entry, Descent, and Landing Phases

The 7 Minutes of Terror

20,000 km/h ($E = 100\%$)
125 km

Entry

~4 minutes

1,500 km/h ($E = 1\%$)
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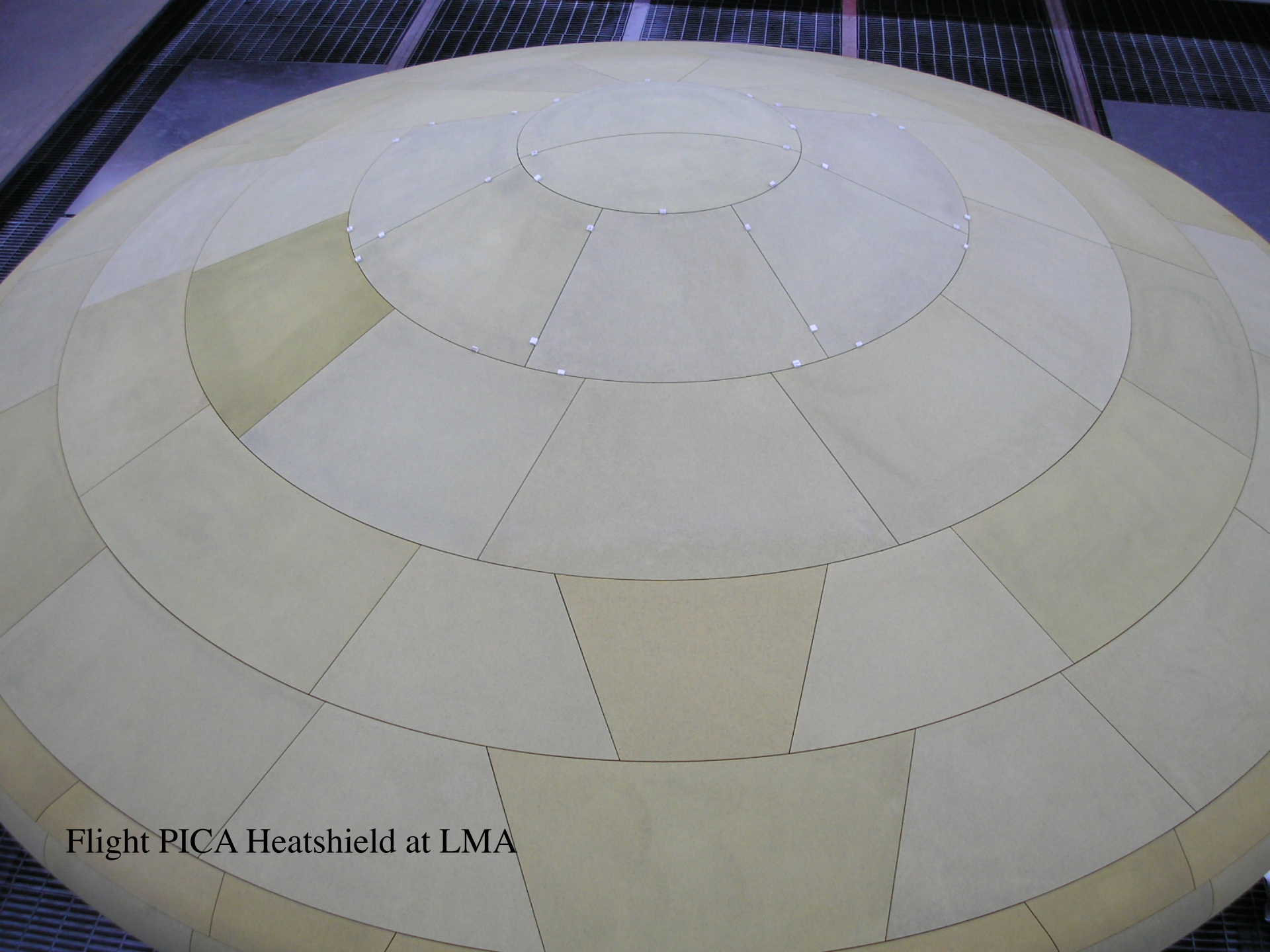




MSL Aeroshell

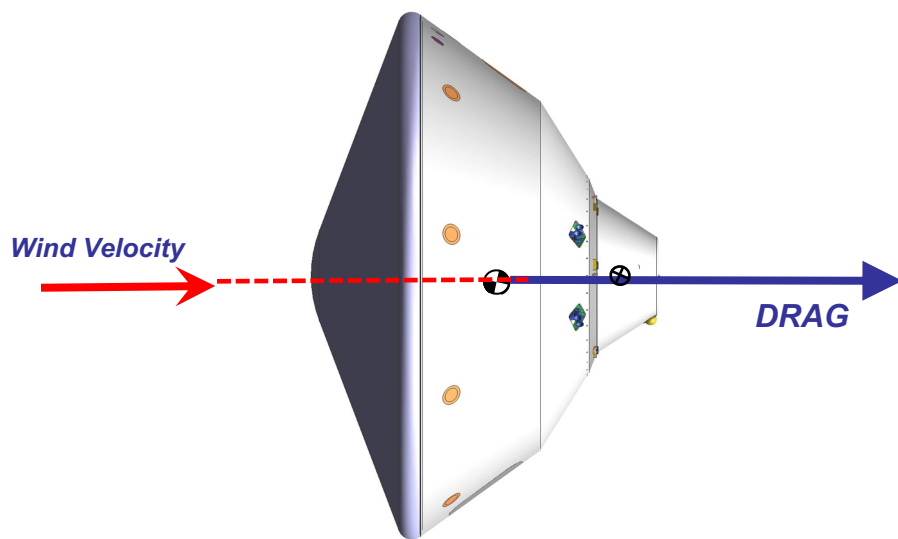




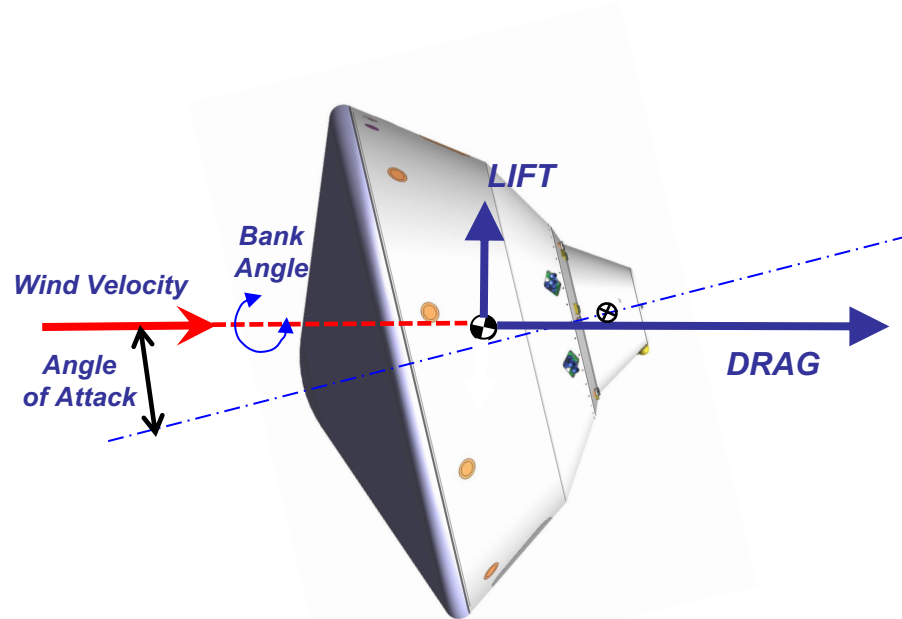


Flight PICA Heatshield at LMA

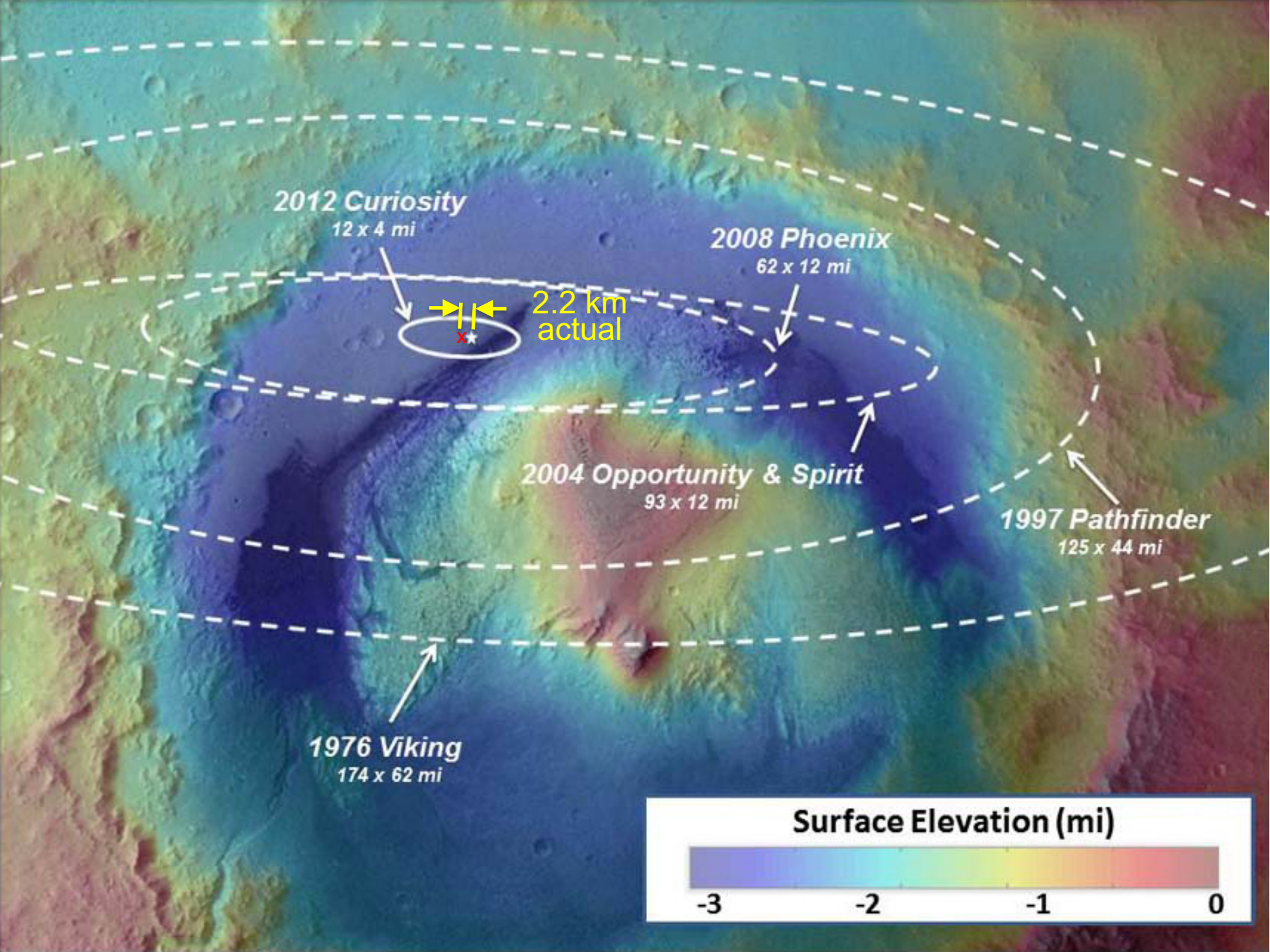
Ballistic vs. Lifting Entry



Ballistic Entry
(Pathfinder/MER/Phoenix)



Lifting Entry
(Viking, Curiosity)





Entry, Descent, and Landing Phases

20,000 km/h ($E = 100\%$)

125 km

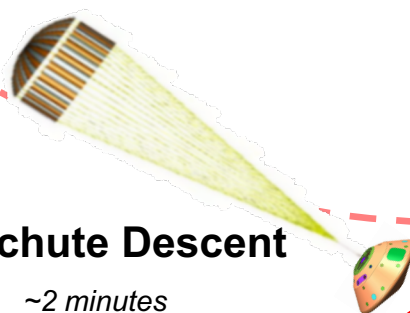


Entry

~4 minutes

1,500 km/h ($E = 1\%$)

10 km



Parachute Descent

~2 minutes

Powered Descent

300 km/h ($E = 0.02\%$)

1.8 km



Landing

~1 minute

Touchdown

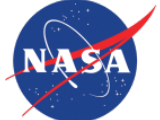
3 km/h ($E = 2 \cdot 10^{-6}\%$)





World's Largest Supersonic Parachute



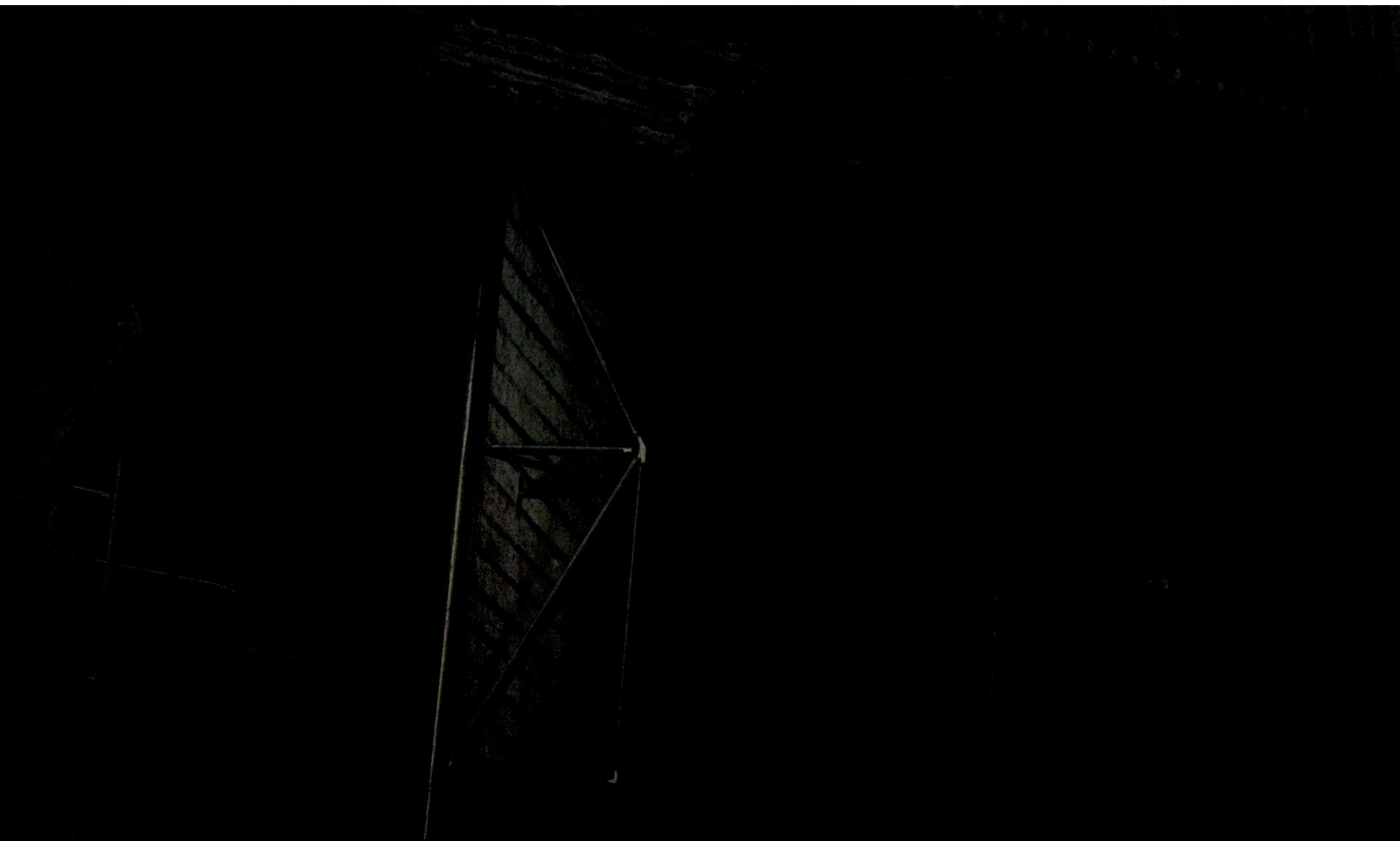


World's Largest Supersonic Parachute





World's Largest Supersonic Parachute





Entry, Descent, and Landing Phases

20,000 km/h ($E = 100\%$)
125 km

Entry
~4 minutes

1,500 km/h ($E = 1\%$)
10 km

Parachute Descent
~2 minutes

300 km/h ($E = 0.02\%$)
1.8 km

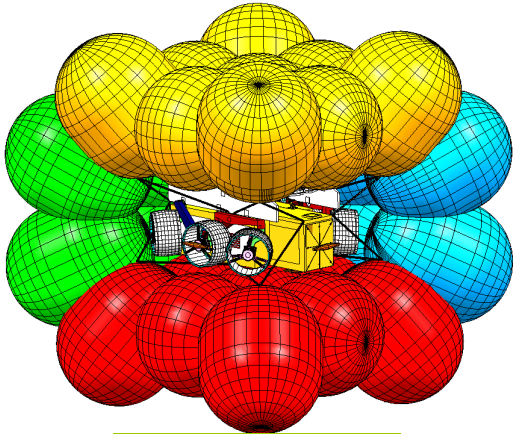
Powered Descent
~1 minute

Landing
3 km/h ($E = 2 \cdot 10^{-6}\%$)





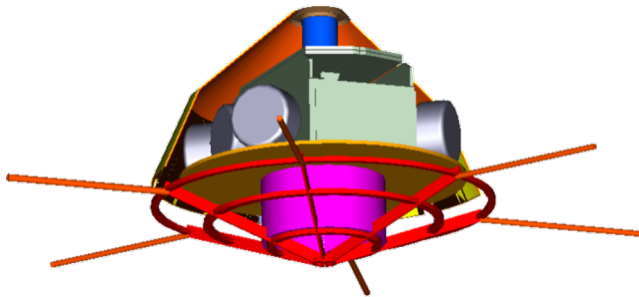
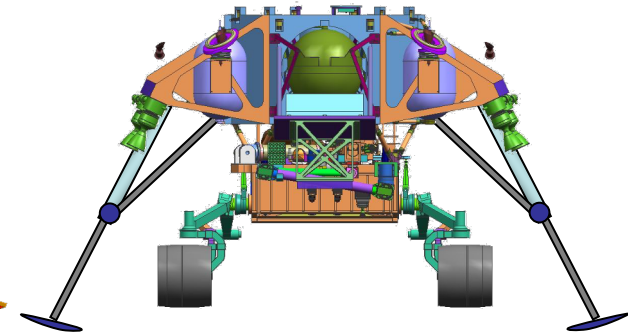
How to land a 1 ton rover?



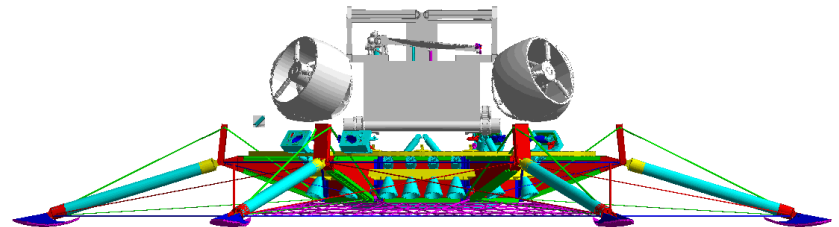
Airbags



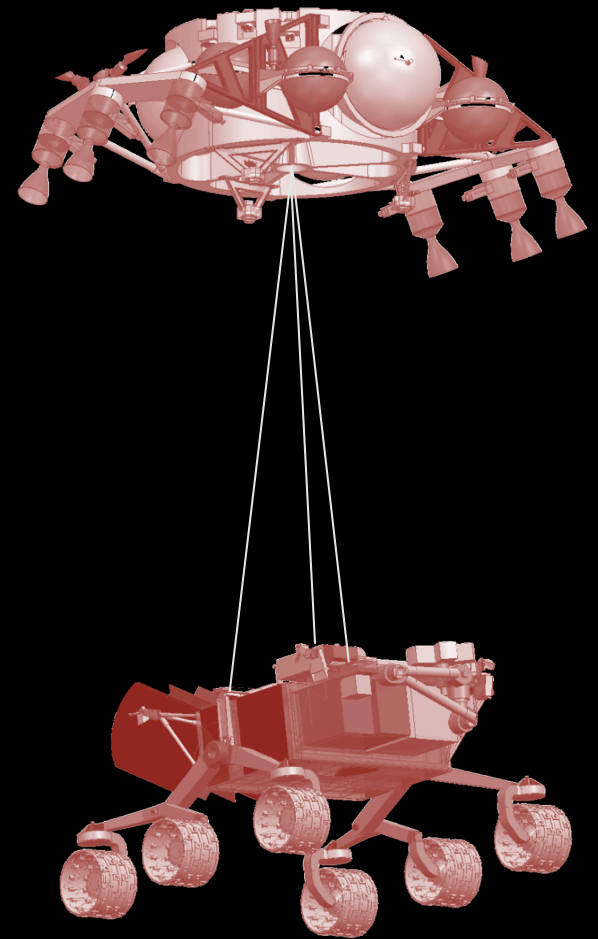
Legs

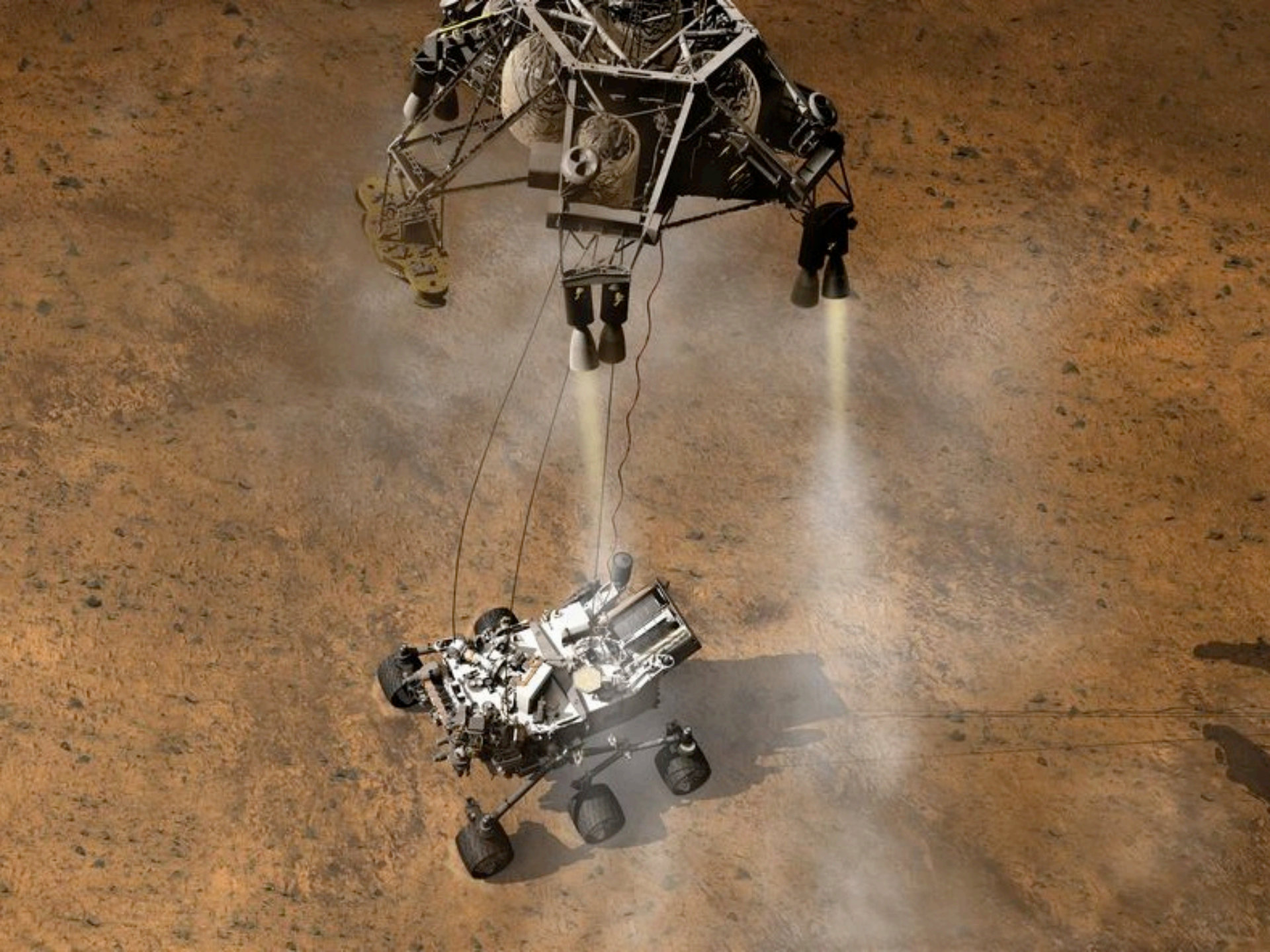


Pallet



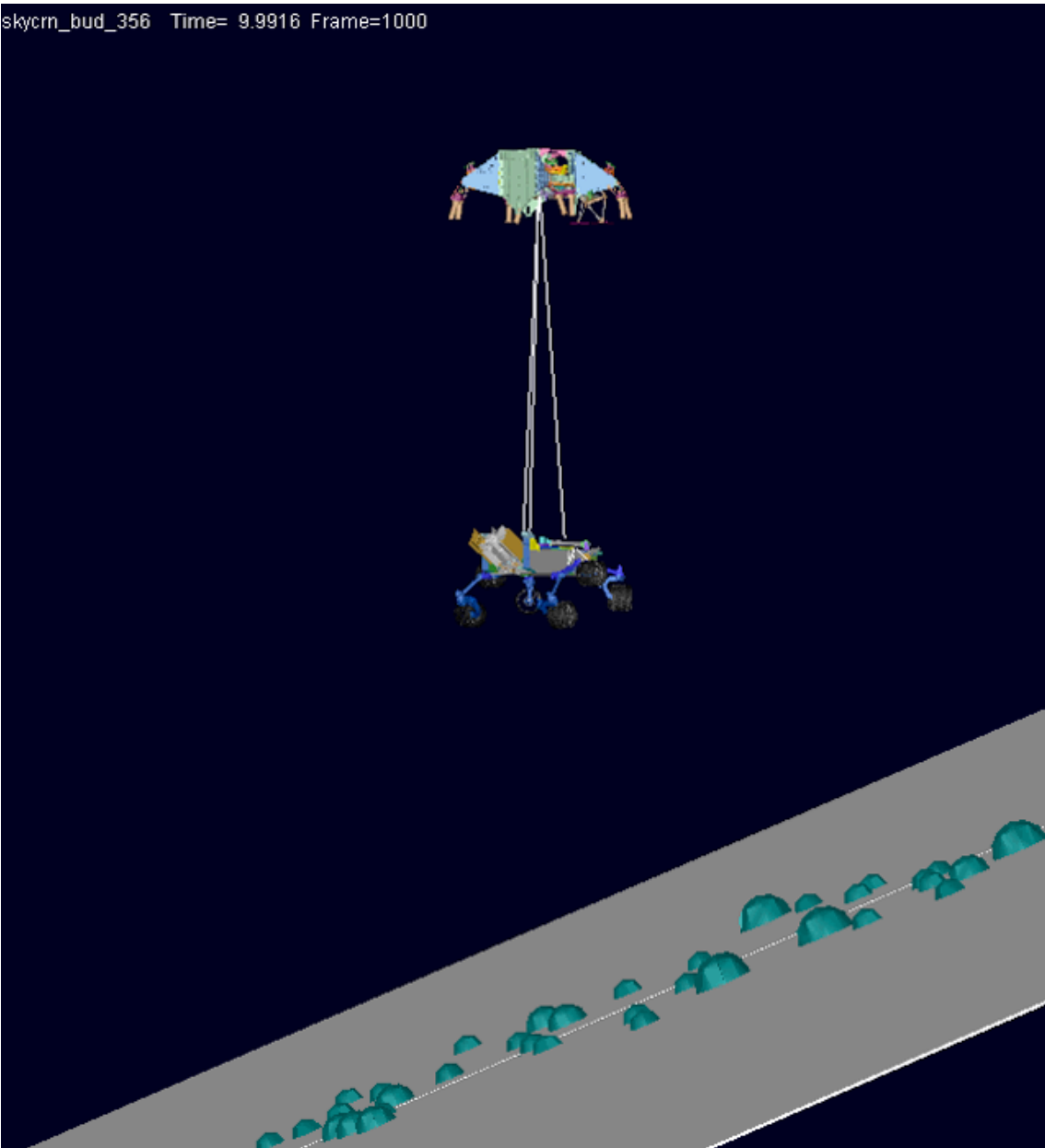
2003: The Skycrane maneuver is born





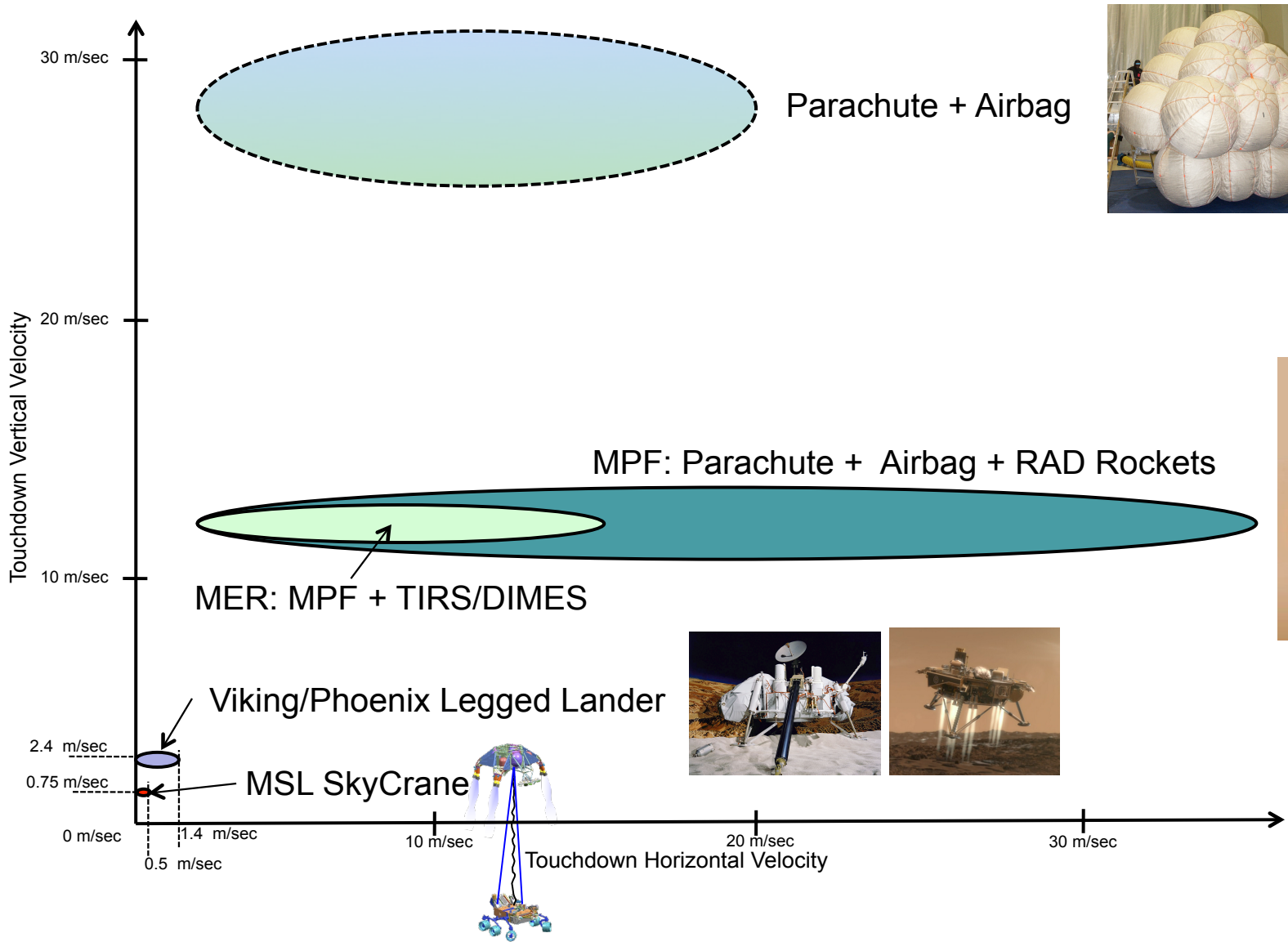


Continued Control Through Touchdown



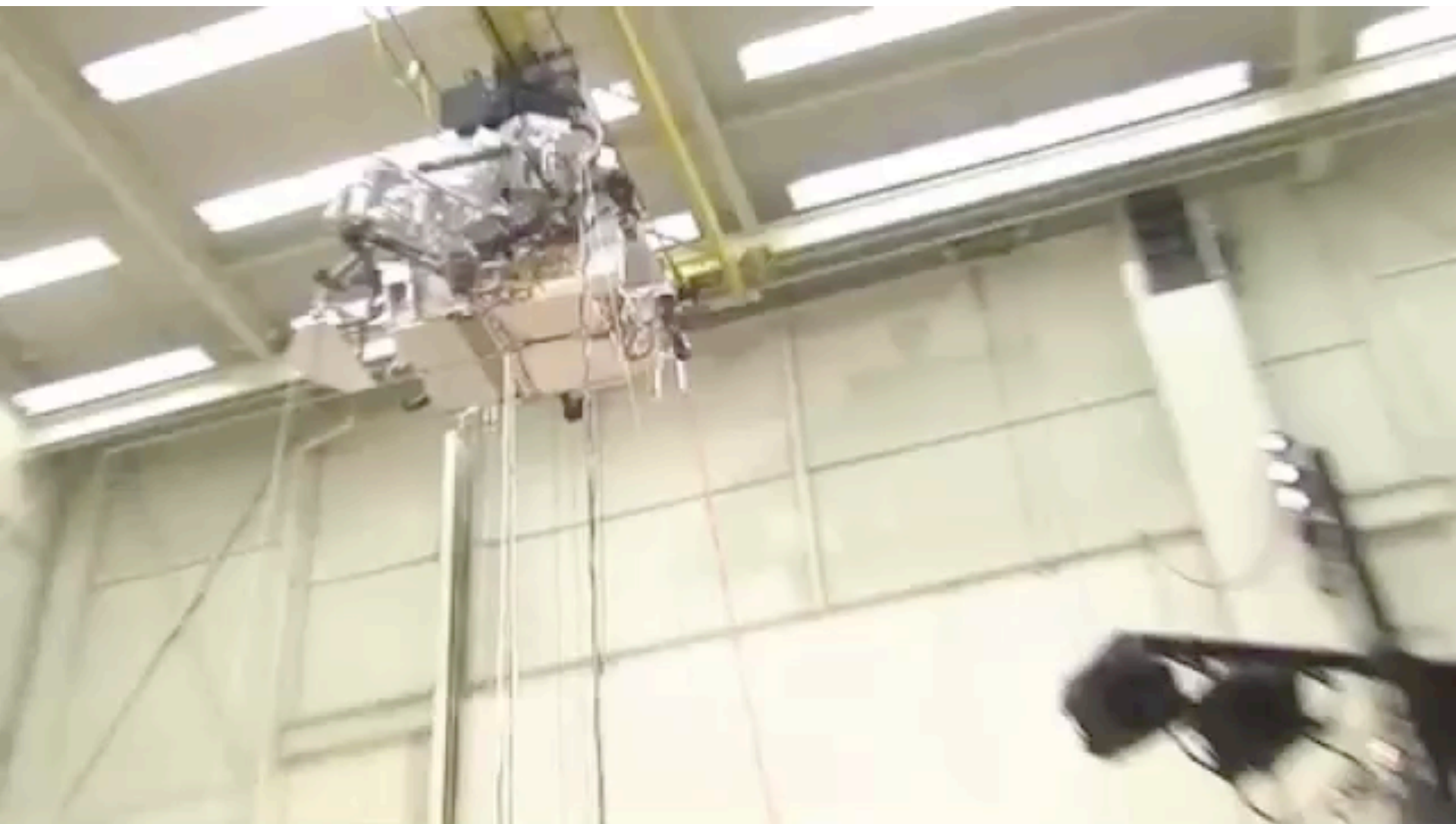


History of Mars Touchdown Velocities



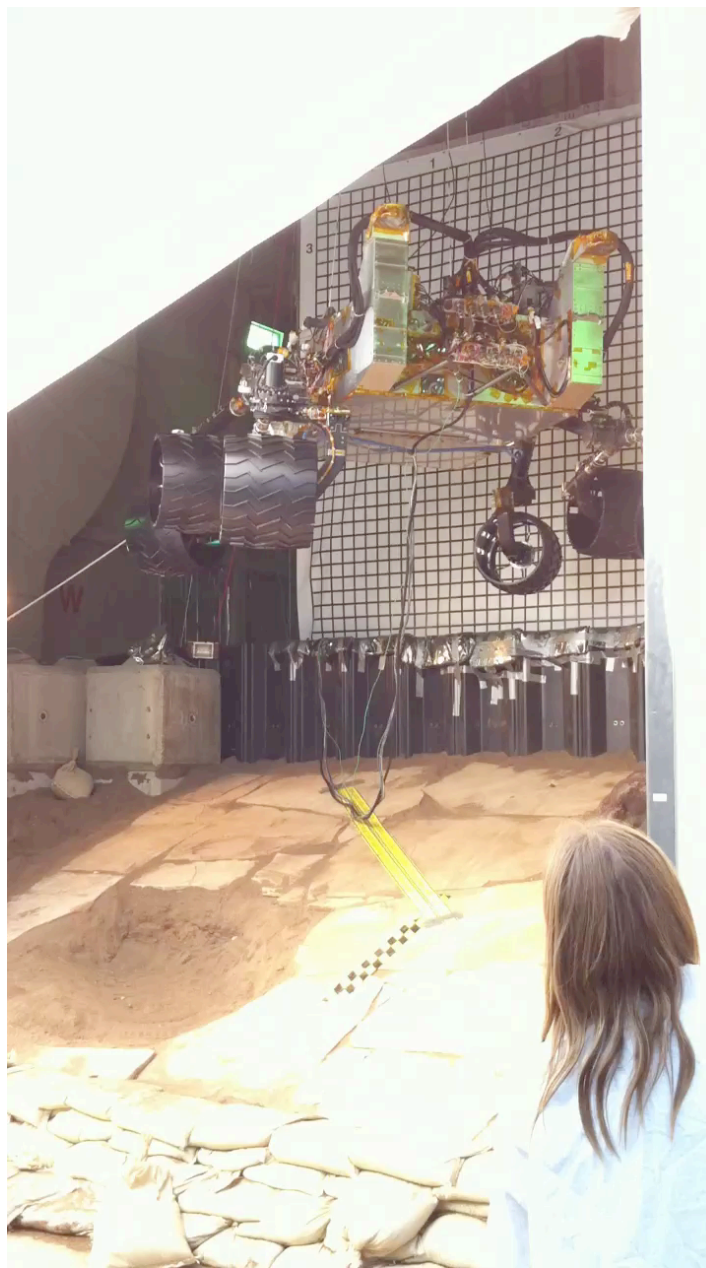


Full Motion Test





Touchdown Tests





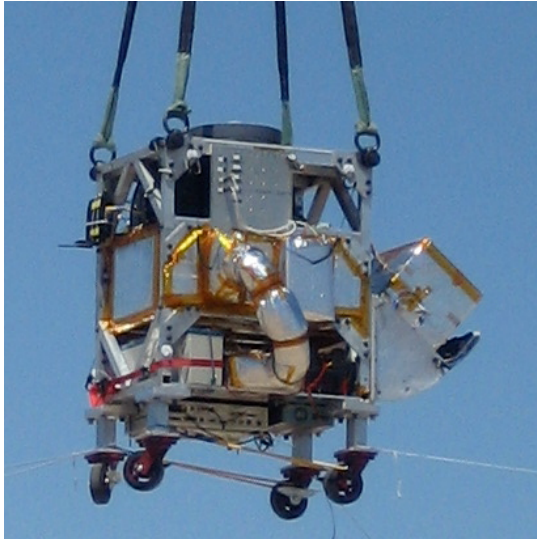
Curiosity





Radar Field Tests

China Lake Echo Towers

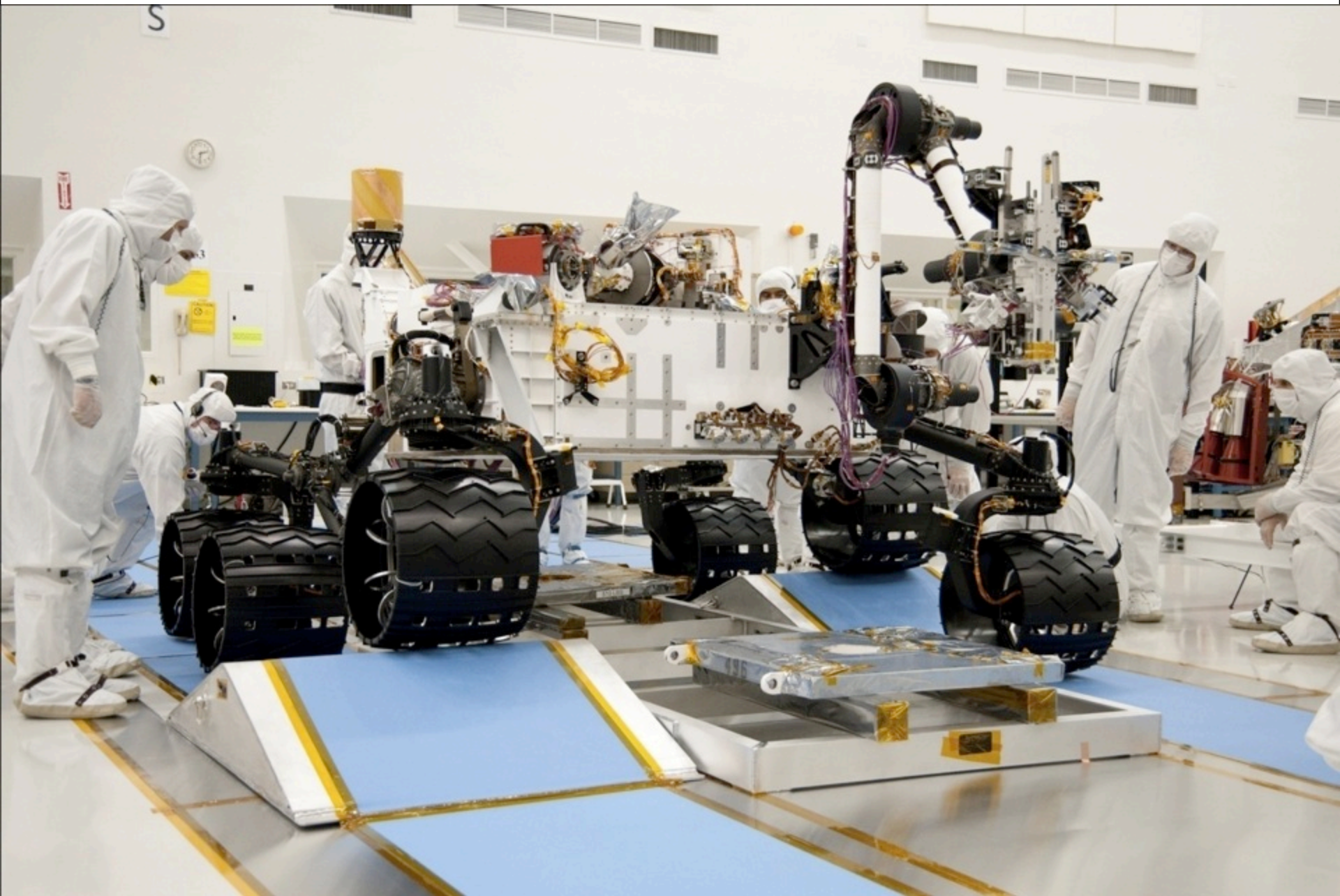


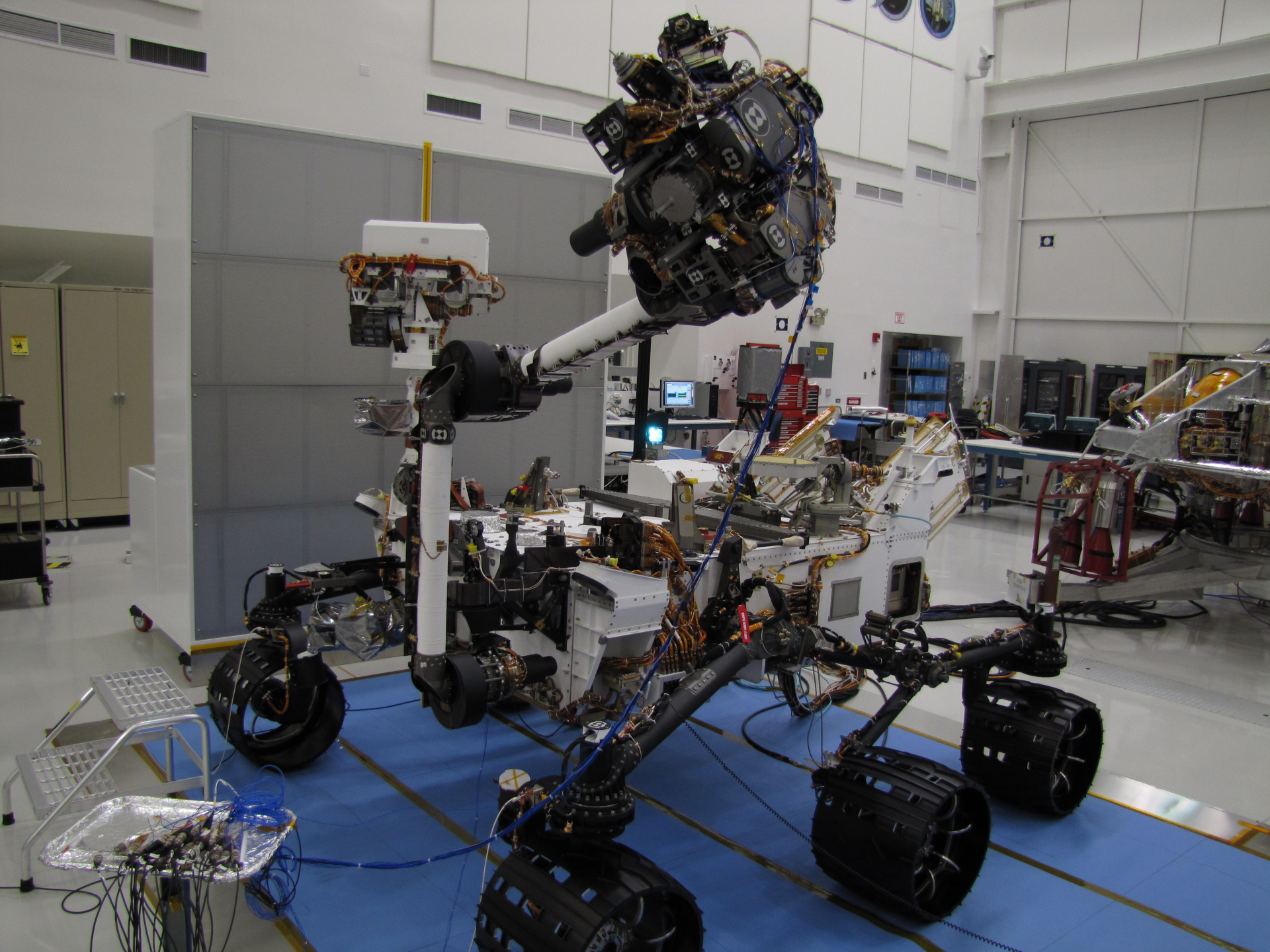
NASA Dryden Flight
Research Center F/A-18

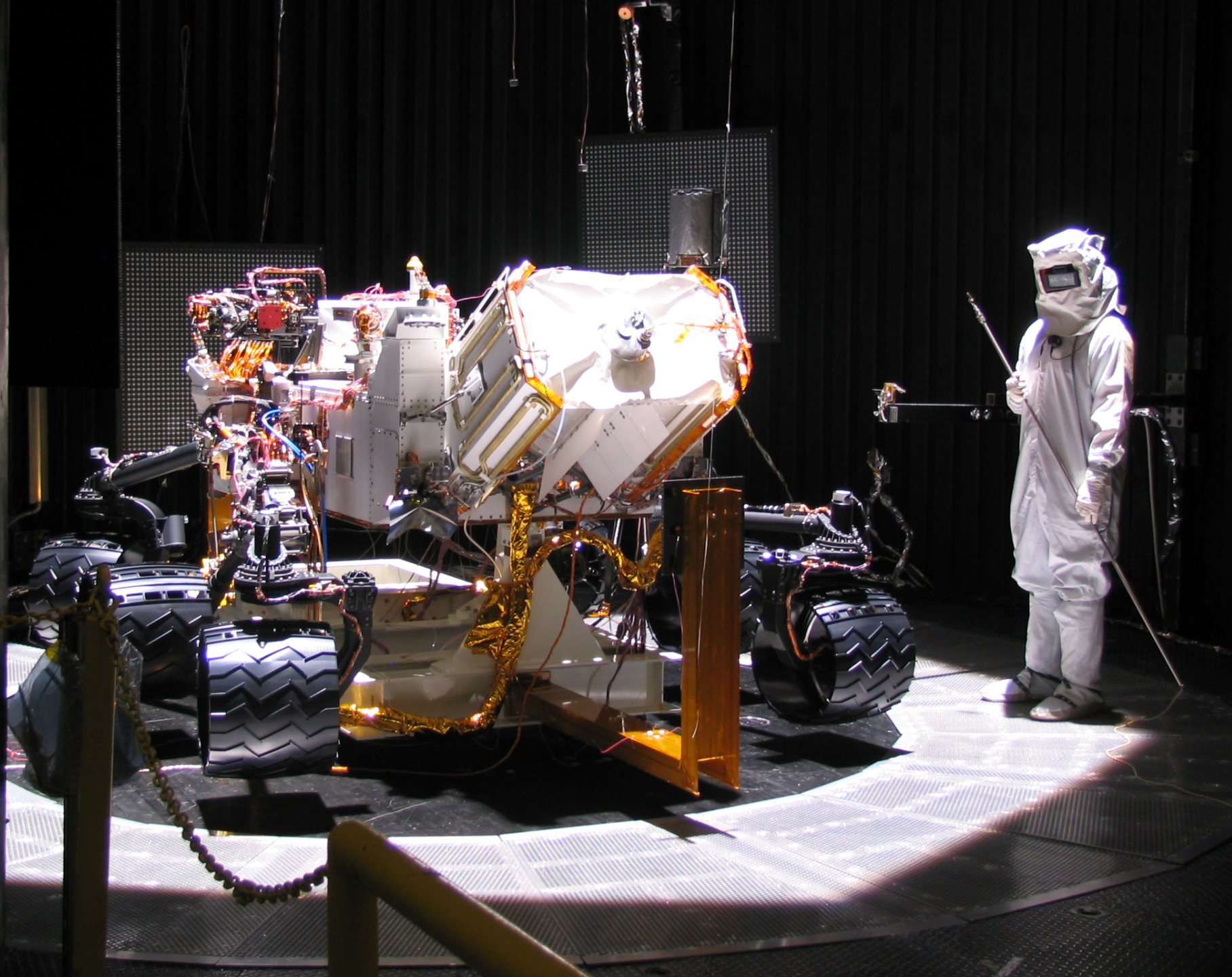


Eurocopter AS350 AStar Helicopter





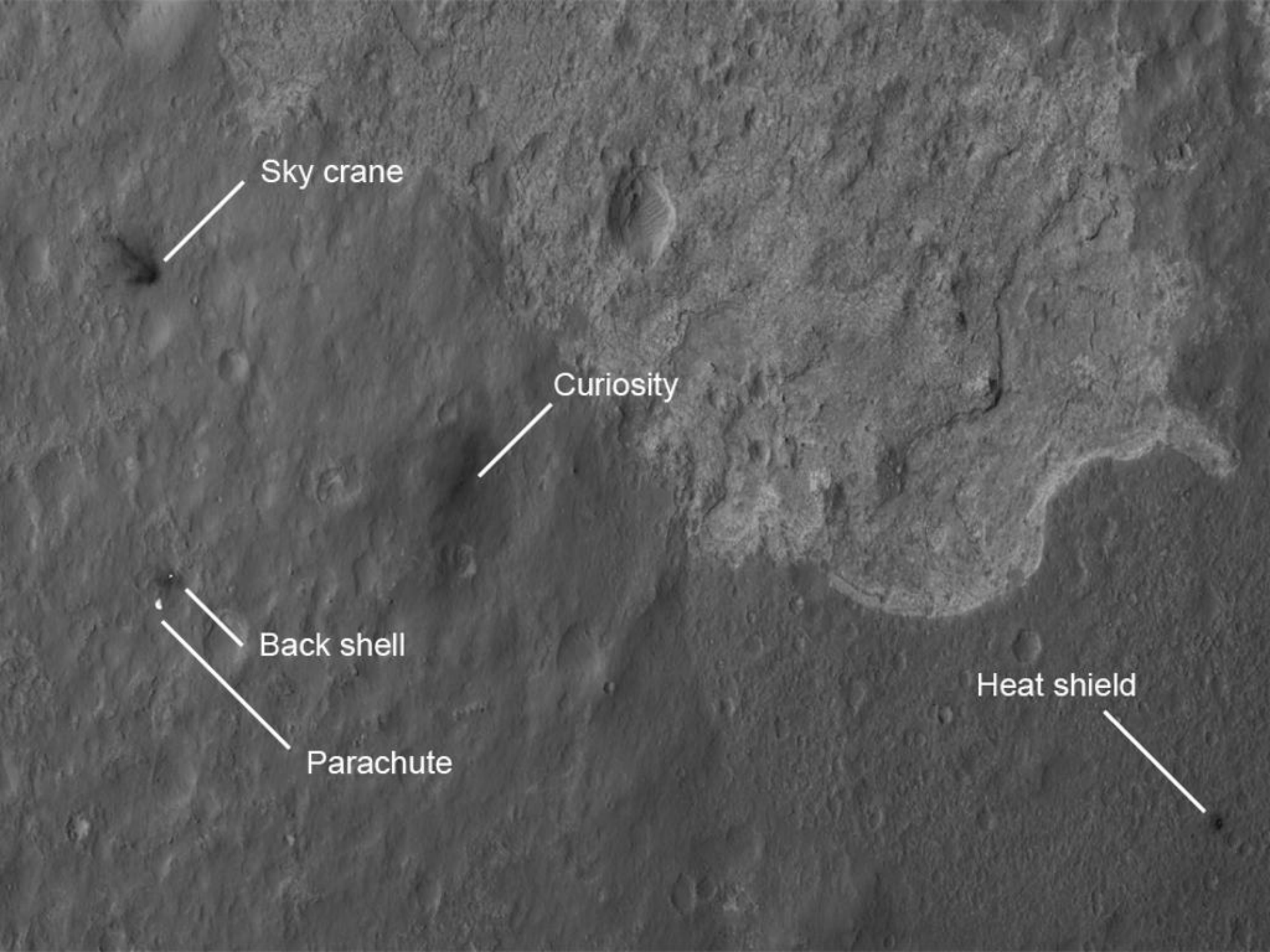












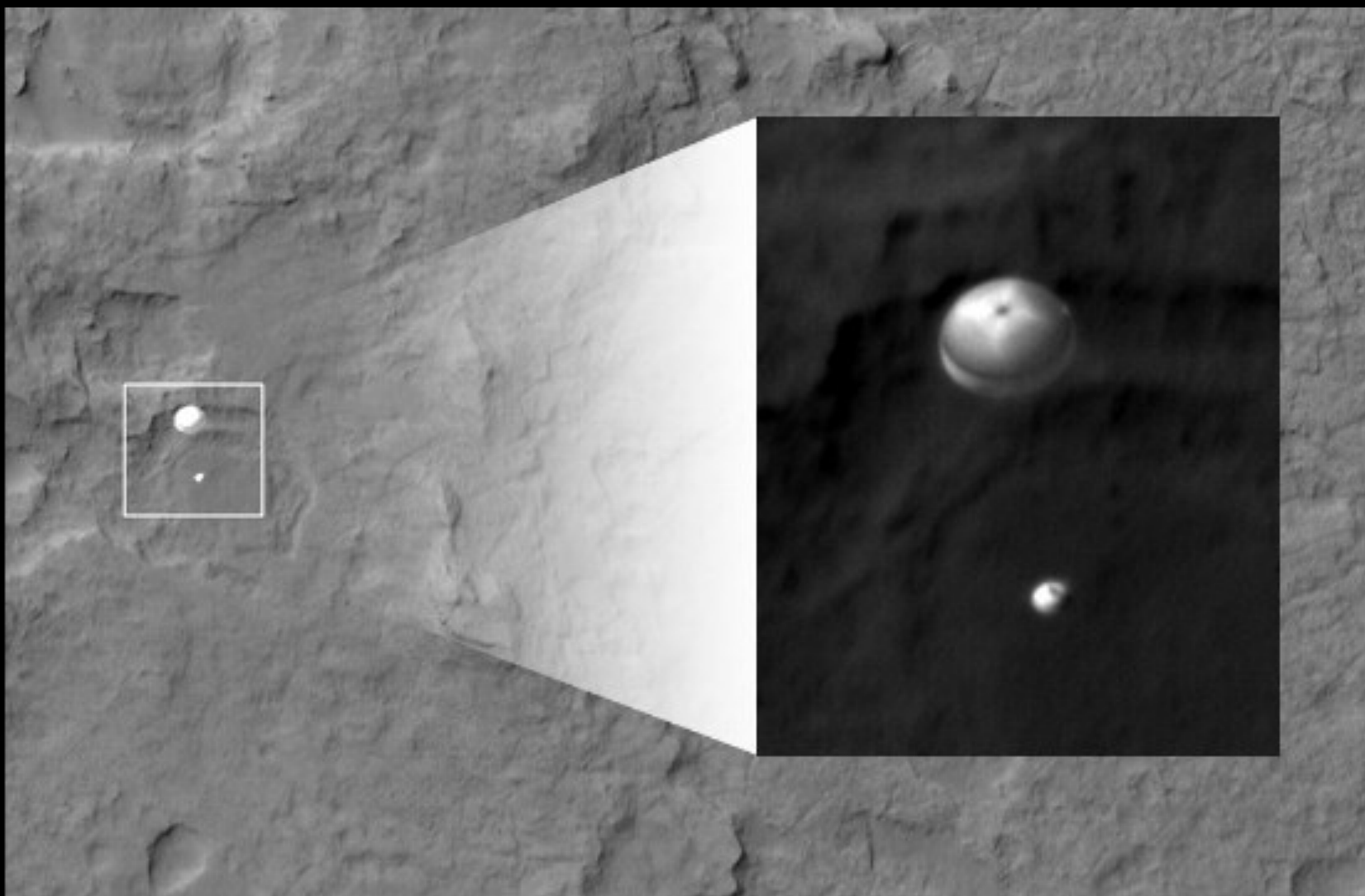
Sky crane

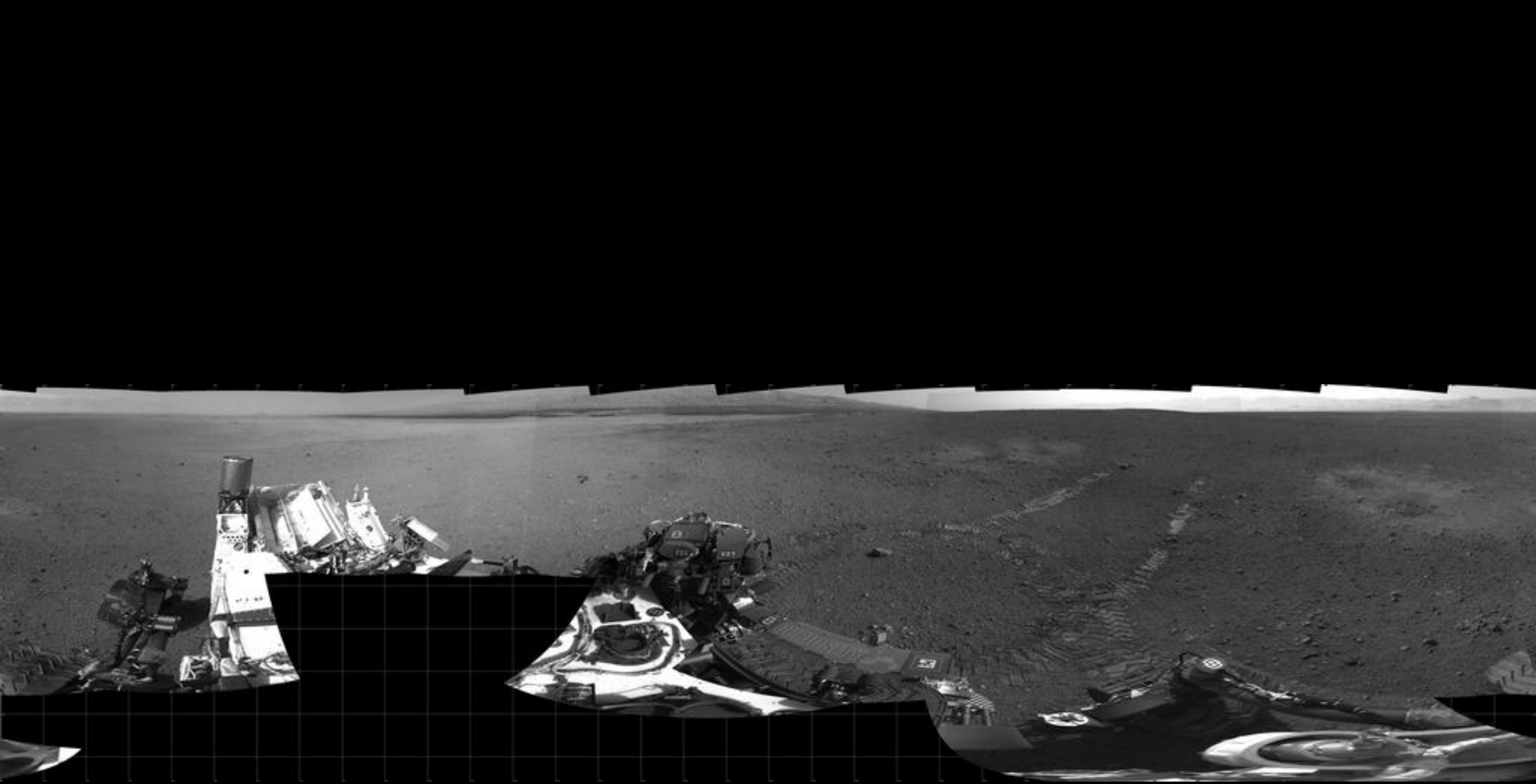
Curiosity

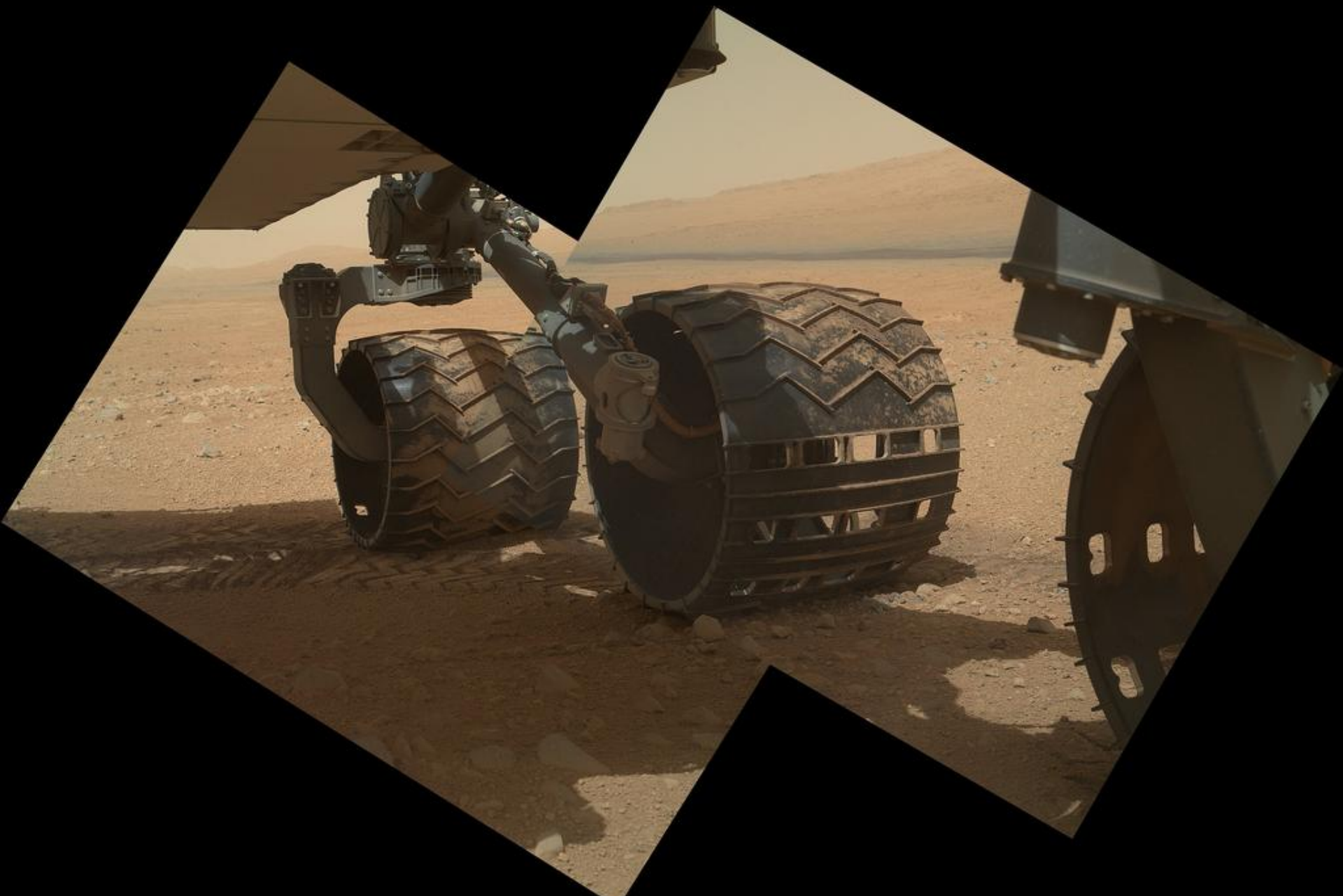
Back shell

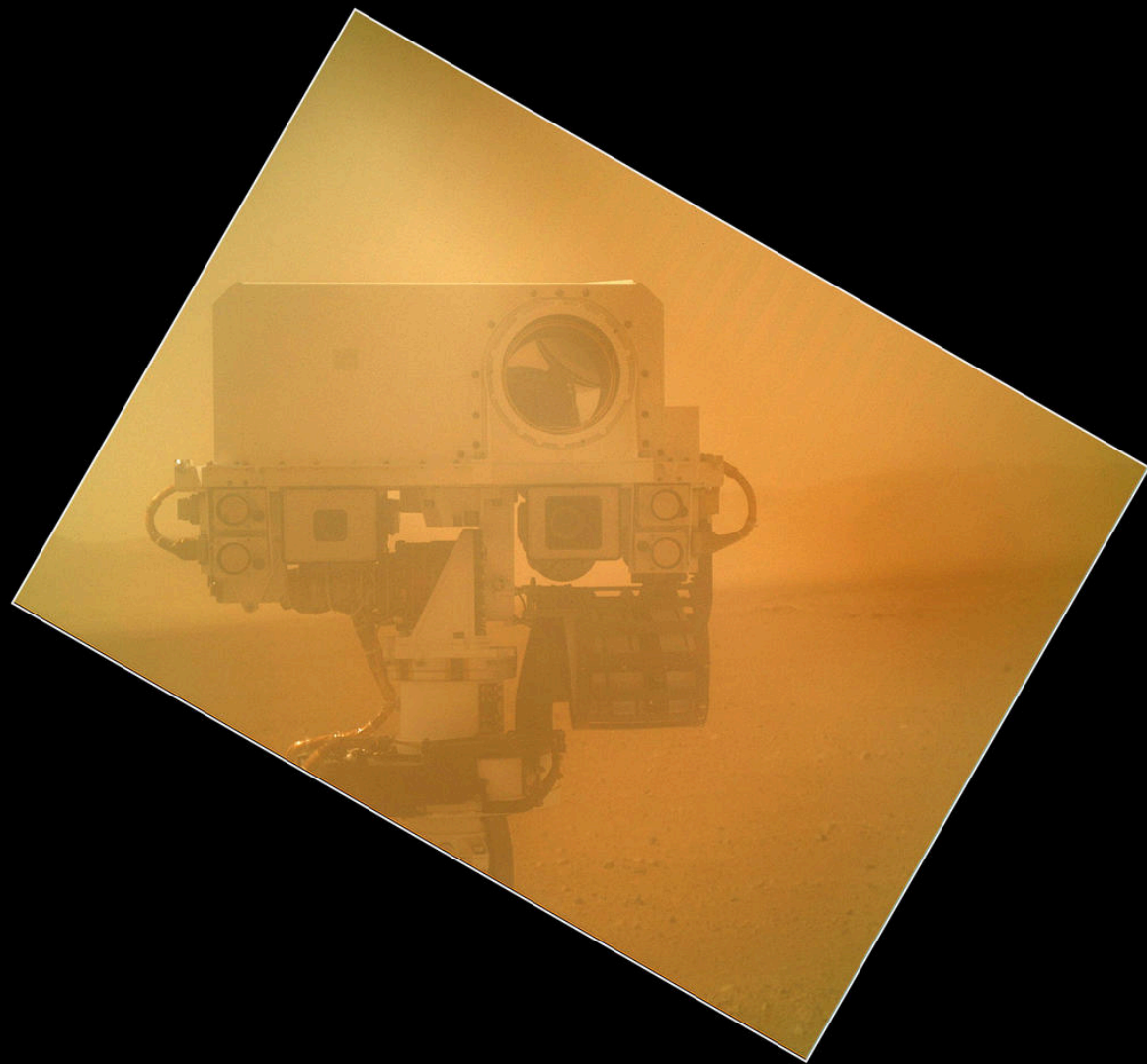
Parachute

Heat shield









Curiosity: Whale Rock



Credits: NASA-JPL-CALTECH/MSSS



Monte Sharp

